Effects of Three Lingual Conditions on Submental Muscle Activity in Healthy Young and Old Adults

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This dissertation titled
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Abstract

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Because swallowing is a complex neurological event, swallowing disorders (dysphagia) occurs after damage to the oral, pharyngeal, and/or esophageal musculature or the underlying neural pathways, and affects approximately 20% of Americans 50 years or older. An effective swallow (transfer of food or liquid from the mouth to the stomach) involves three stages: oral, pharyngeal, and esophageal. This study focuses on muscles that contribute to both the oral and pharyngeal stages of swallowing: submental and lingual muscles.

The purpose of this study was to examine submental muscle activation using surface electromyography (sEMG), and lingual strength using lingual pressure during three intraoral lingual conditions in 25 young (18 to 40 years) and 24 older (60 years and above) healthy participants. The experimental lingual conditions in this study were chosen because they reflect lingual movements that are or can be routinely adopted during lingual exercise programs in dysphagia treatment. The three lingual conditions in this study are intraoral lingual elevation to the hard palate, lingual protrusion, and lingual depression. This study also examined the effects of age and gender on submental muscle activity and lingual pressure.
This study found that there was no difference in mean submental muscle activation, as measured by sEMG, between young and older healthy adults during the intraoral maximum isometric pressure (MIP) lingual conditions. However, the mean maximum submental muscle activity was higher in women than in men. During the MIP lingual conditions, mean peak lingual pressure was greater in young healthy adults, but no difference was observed between men and women. The MIP lingual condition involving lingual protrusion resulted in the greatest activation of submental muscles, whereas the lingual depression condition resulted in the generation of the highest peak lingual pressure. The outcomes of this study lay the foundation for further research not only in normative populations, but also in individuals with dysphagia.
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Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>3</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>5</td>
</tr>
<tr>
<td>List of Tables</td>
<td>10</td>
</tr>
<tr>
<td>List of Figures</td>
<td>11</td>
</tr>
<tr>
<td>Chapter 1: Introduction</td>
<td>13</td>
</tr>
<tr>
<td>Chapter 2: Review of Literature</td>
<td>17</td>
</tr>
<tr>
<td>Submental Musculature</td>
<td>17</td>
</tr>
<tr>
<td>Structure of the submental musculature</td>
<td>17</td>
</tr>
<tr>
<td>Role of the submental musculature in oropharyngeal swallowing</td>
<td>20</td>
</tr>
<tr>
<td>The Tongue</td>
<td>21</td>
</tr>
<tr>
<td>Extrinsic muscles of the tongue</td>
<td>22</td>
</tr>
<tr>
<td>Intrinsic muscles of the tongue</td>
<td>24</td>
</tr>
<tr>
<td>Coordination between the extrinsic and intrinsic lingual muscles for lingual movements</td>
<td>26</td>
</tr>
<tr>
<td>Lingual movements in swallowing</td>
<td>27</td>
</tr>
<tr>
<td>Muscle Fibers in Lingual and Submental Musculature</td>
<td>29</td>
</tr>
<tr>
<td>Electromyography and Submental Muscle Activation</td>
<td>30</td>
</tr>
<tr>
<td>Lingual Strength Measurements</td>
<td>34</td>
</tr>
<tr>
<td>Submental Muscle Activation During Lingual Functions</td>
<td>36</td>
</tr>
<tr>
<td>Effects of Age on Submental Muscle Activation and Lingual Strength</td>
<td>37</td>
</tr>
</tbody>
</table>
Effects of age on submental muscle activation as measured by sEMG ................. 38
Effects of age on lingual strength as measured by lingual pressures .................. 38
Effects of Gender on Submental Muscle Activation and Lingual Strength ......... 41
Effects of gender on submental muscle activation as measured by sEMG. .......... 41
Effects of gender on lingual strength as measured by lingual pressures. .......... 41
Lingual Exercises and Maneuvers in Dysphagia Treatment .................................. 42
Repeated effortful swallow .................................................................................... 43
Lingual strengthening exercises ........................................................................... 44
Effects of Lingual Conditions on Lingual Strength and Submental Muscle Activation .......................................................................................................................... 46
Research Aims of the Current Study .................................................................. 47
Research aims and hypotheses ............................................................................. 49
Chapter 3: Method ............................................................................................... 55
Participants ............................................................................................................. 55
Set-Up of Instrumentation .................................................................................... 55
Instrumentation for recording submental muscle activation .................................. 56
Instrumentation for recording lingual pressures. .................................................... 57
Procedure ............................................................................................................... 59
Participant screening ............................................................................................. 59
Placement of submental sEMG electrode .............................................................. 60
Placement of the three-bulb tongue array .............................................................. 62
Bite block and placement of sEMG electrode over the masseter ......................... 63
Experimental protocol........................................................................................................63
Data Analysis......................................................................................................................66
Submental sEMG measurements ..................................................................................66
Lingual pressure measurements ....................................................................................67
Reliability ..........................................................................................................................68
Statistical Analysis ...........................................................................................................69
Research aim I ..................................................................................................................69
Research aim II ................................................................................................................69
Research aim III ..............................................................................................................69
Research aim IV ..............................................................................................................70
Chapter 4: Results ............................................................................................................71
Research Aim I: Submental Muscle Activation and Lingual Pressures .......................71
Research Aim II: Effects of Age, Gender, and Lingual Condition on Submental Muscle
Activation as Measured by sEMG ..................................................................................75
  Age and gender ..............................................................................................................75
  Lingual condition .........................................................................................................78
Research Aim III: Effect of Age, Gender, and Lingual Condition on Lingual Strength
as Measured by Lingual Pressures ................................................................................83
  Age and gender ..............................................................................................................83
  Lingual condition .........................................................................................................86
Research Aim IV: Correlation Between Submental sEMG Measures and Lingual
Pressures .........................................................................................................................89
### List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1:</td>
<td>Mean and Standard Error of Normalized Maximum sEMG for Maximum Isometric Pressure Lingual Conditions and Swallowing Tasks</td>
<td>72</td>
</tr>
<tr>
<td>Table 2:</td>
<td>Mean Normalized Maximum sEMG for the Two Age and Gender Groups During Maximum Isometric Pressure Lingual Conditions and Swallowing Tasks</td>
<td>73</td>
</tr>
<tr>
<td>Table 3:</td>
<td>Mean and Standard Error of Anterior Peak Lingual Pressure (kPa) for Maximum Isometric Pressure Lingual Conditions and Swallowing Tasks</td>
<td>74</td>
</tr>
<tr>
<td>Table 4:</td>
<td>Mean Anterior Peak Lingual Pressure (kPa) for the Two Age and Gender Groups During Maximum Isometric Pressure Lingual Conditions and Swallowing Tasks</td>
<td>75</td>
</tr>
</tbody>
</table>
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>The lateral view of the anterior belly of the digastric</td>
<td>19</td>
</tr>
<tr>
<td>Figure 2</td>
<td>The lateral view of the mylohyoid and the geniohyoid</td>
<td>20</td>
</tr>
<tr>
<td>Figure 3</td>
<td>The extrinsic and intrinsic muscles of the tongue</td>
<td>25</td>
</tr>
<tr>
<td>Figure 4</td>
<td>The three clips and surface electrode used for measuring submental surface electromyography</td>
<td>57</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Three-bulb tongue array</td>
<td>59</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Placement of surface electromyography electrode</td>
<td>61</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Mean log transformed normalized maximum sEMG during the three maximum isometric pressure lingual conditions for young and older healthy adults</td>
<td>77</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Mean log transformed normalized maximum sEMG during the three maximum isometric pressure lingual conditions for men and women</td>
<td>78</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Mean log transformed normalized maximum sEMG for the three maximum isometric pressure lingual conditions</td>
<td>80</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Interaction between age and lingual condition for log transformed normalized maximum submental surface electromyography</td>
<td>82</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Mean peak lingual pressures (kPa) during the three maximum isometric pressure lingual conditions for young and older healthy adults</td>
<td>84</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Mean peak lingual pressures (kPa) during the three maximum isometric pressure lingual conditions for men and women</td>
<td>85</td>
</tr>
</tbody>
</table>
Figure 13: Mean peak lingual pressure (kPa) for the three maximum isometric pressure lingual conditions.................................................................87

Figure 14: Interaction between age and lingual condition for mean peak lingual pressure ......................................................................................................................89
Chapter 1: Introduction

An effective swallow encompasses complex physiological events that are interdependent and rely on oral, pharyngeal, and esophageal musculature (Ertekin & Aydogdu, 2003), and the integrity of the neural control mechanism. The complexity of oropharyngeal swallowing is highlighted by the fact that effective transition of the bolus through the oral and pharyngeal stages depends on approximately 26 muscles and five cranial nerves (Sawczuk & Mosier, 2001). The musculature constituting the swallowing mechanism is innervated by cranial nerves. The integrity of the striated musculature subserving swallowing function is essential to safe and effective transfer of boluses from the mouth to the esophagus, because impaired contraction of these muscles can lead to reduced range and force of lingual, pharyngeal, and hyolaryngeal movements. Such impairments, in turn, can cause decreased oral-pharyngeal clearance and increased risk for spillage of food and liquid into the airway.

The oral stage of swallowing is voluntary in nature, while the pharyngeal stage is predominantly reflexive. However, the pharyngeal stage involves not only the pharyngeal and laryngeal musculature, but also the lingual and suprathyroid muscles (Ertekin & Aydogdu, 2003). Normal lingual function is imperative for formation and control of the bolus, bolus propulsion through the oral and pharyngeal cavity, and bolus clearance (Clark, Henson, Barber, Stierwalt, & Sherill, 2003; Robbins, Levine, Wood, Roecker, & Luschei, 1995). The submental muscles, which constitute the floor of the mouth, have an influence on swallowing events that are integral for a safe swallow, such as hyolaryngeal
excursion and upper esophageal sphincter opening (Huckabee, Butler, Barclay, & Jit, 2005).

The contributions and interactions among the muscles in swallowing can be quantified using different methods. Electromyography (EMG) and tongue manometry are two methods used to measure the effects of oropharyngeal muscle contraction during swallowing. The use of tongue manometry to measure lingual pressures generated during swallowing and during therapy exercises are well documented in swallowing research (Clark et al., 2003; Huckabee et al., 2005; Robbins et al., 1995, 2005, 2007). Electromyographic measurements represent the muscle activity during muscular contraction over a specific period. Surface EMG (sEMG) involves recording such muscle activity with surface electrodes; sEMG is a reliable, simple, and noninvasive method used in both clinical evaluation and feedback, as well as in swallowing research (Palmer, Luschei, Jaffe, & McCulloch, 1999; Vaiman, Eviatar, & Segal, 2004b).

Placing surface electrodes over the submental muscles is a way of quantifying the contributions from the muscles that form the “leading complex” in swallowing (Crary & Groher, 2000, p. 118). Submental sEMG can also record the onset and offset of submental muscle activity (Perlman, Palmer, McCulloch, & VanDaele, 1999). Thus, submental sEMG measures would provide pertinent information regarding the initiation, duration, and amplitude of submental muscle activation during swallowing (Ertekin & Aydogdu, 2003), and during lingual conditions.

In the present study, sEMG was recorded from the submental muscle area as an index of mylohyoid, geniohyoid, and anterior digastric contraction (Vaiman et al.,
These muscles form the floor of the mouth and are attached to the hyoid bone; therefore, active contraction of the submental area contributes to hyolaryngeal excursion during swallowing. Even though submental sEMG primarily represent properties of the submental muscles, it is also represents “...some degree of input from intrinsic lingual muscles” (Huckabee et al., 2005, p. 2148).

Research has established that the muscles subserving the oral and pharyngeal stages of swallowing can be influenced by anatomical, physiological, and neurological changes (Robbins et al., 1995). However, to our knowledge, research that has examined submental sEMG measures during swallowing and during lingual exercise conditions in healthy adults is limited. For example, although previous research has examined lingual pressures in normal and dysphagic populations, research that has simultaneously recorded submental sEMG and lingual pressures during lingual movements adopted in treatment exercises is scarce. This study aims to describe submental activation using sEMG during swallowing and during maximum isometric pressure (MIP) lingual conditions that involve intraoral lingual movement in three directions. In addition to quantifying submental activation during lingual movements in directions that can be adopted for lingual strengthening exercises during rehabilitation, this study examined the effects of three MIP lingual conditions, which involve lingual movement in three directions (depression, elevation, and protrusion), on submental muscle activation and lingual strength. Advanced knowledge about the relationship between lingual pressure and submental muscle activation will inform development of lingual exercise regimens that target both groups of muscles. Considering the close physical proximity and the
interdependence of these two sets of muscles in swallowing, it can be speculated that lingual exercises designed to increase lingual muscle strength could potentially have an effect on submental muscle activation, i.e., a possible “dual effect.” This study also examined the effects of age and gender on the dependent variables, submental sEMG and lingual pressures. This research hopes to contribute to the body of research in swallowing and swallowing disorders by examining the activation of important oropharyngeal muscles during lingual conditions that potentially could be adopted clinically in lingual strengthening exercises.
Chapter 2: Review of Literature

In an effort to better understand submental muscle activation and lingual pressures during oropharyngeal swallowing and during lingual exercises, this section will review and summarize relevant research in the following areas: Structure of submental and lingual musculature, and their functions in swallowing; measurement of submental muscle activation and lingual muscle strength using sEMG and lingual pressure measures, respectively; the effects of age and gender on submental sEMG and lingual pressure; and, the effects of strengthening exercise conditions on submental, lingual, and overall swallowing function.

Submental Musculature

The muscles that constitute the submental (submandibular) musculature are the mylohyoid, geniohyoid, and anterior belly of the digastric. These muscles form the floor of the mouth (Ertekin & Aydogdu, 2003) and connect the hyoid to the mandible (Bosma, Donner, Tanaka, & Robertson, 1986). The submental muscles have an influence on oropharyngeal swallowing events such as hyolaryngeal excursion (Huckabee et al., 2005). The three submental muscles also constitute the suprahyoid musculature. The suprahyoid musculature consists of four pairs of muscles, namely the anterior and posterior belly of the digastric, stylohyoid, mylohyoid, and geniohyoid, and contributes to hyoid elevation during swallowing (Drake, Vogl, & Mitchell, 2005).

Structure of the submental musculature. As previously stated, three muscles constitute the submental musculature. The anterior belly of the digastric originates from the digastric fossa on the mandible and attaches to the tendon that connects the two
bellies of the muscle to the hyoid (Drake et al., 2005). This muscle is innervated by the trigeminal nerve. Along with the posterior belly of the digastric, the contraction of the anterior belly of the digastric contributes to raising the hyoid bone, and opening the oral cavity by lowering the mandible (Drake et al., 2005). The mylohyoid originates from the lingual surface of the mandible and inserts into the hyoid. This muscle is located superiorly to the anterior belly of the digastric, and along with the other suprahyoid muscles contributes to the elevation of the hyoid (Drake et al., 2005). The mylohyoid is also innervated by the trigeminal nerve (Bosma et al., 1986). The geniohyoid originates from the lingual surface of the symphysis of the mandible and inserts into the hyoid bone (Drake et al., 2005). On contraction, the geniohyoid elevates the hyoid when the mandibular position is fixed, and depresses the mandible when the hyoid position is fixed (Drake et al., 2005). The branch from the anterior ramus of C1, which courses along with the hypoglossal nerve, innervates the geniohyoid (Drake et al., 2005). Figure 1 illustrates the anterior belly of the digastric, and Figure 2 illustrates the mylohyoid and the geniohyoid.
Figure 1. The lateral view of the anterior belly of the digastric. This figure was published in *Gray’s Anatomy for Students* (2nd ed.), by R. L. Drake, A. W. Vogl, and A. W. M. Mitchell, 2010, p. 954. Copyright 2010 by Elsevier. Reprinted with permission.
Figure 2. The lateral view of the mylohyoid and the geniohyoid. This figure was published in *Gray’s Anatomy for Students* (2nd ed.), by R. L. Drake, A. W. Vogl, and A. W. M. Mitchell, 2010, p. 1040. Copyright 2010 by Elsevier. Reprinted with permission.

**Role of the submental musculature in oropharyngeal swallowing.** The three submental muscles contract simultaneously to initiate swallowing and contribute to laryngeal elevation (Ertekin & Aydogdu, 2003; Logemann, 1998; Miller, 1982). These muscles are primarily responsible for elevating the hyoid and larynx in a superior-anterior direction during swallowing (Spiro, Rendell, & Gay, 1994); this is a physiological event necessary to ensure inversion of the epiglottis and both closure and displacement of the larynx, thereby directing the bolus safely into the upper esophagus rather than the trachea. The contraction of the submental muscles is also one of the factors involved in
the opening the upper esophageal sphincter during swallowing (Huckabee et al., 2005; Logemann, 1998). Amongst other lingual muscles, these muscles also contract during lingual elevation to the hard palate (Ertekin & Aydogdu, 2003). During voluntary swallowing, the submental muscles are activated and controlled by cortical input and input from the central pattern generator, which is located in the medulla (Ertekin & Aydogdu, 2003).

Spiro et al. (1994) examined the contribution of submental muscles to hyoid elevation using intramuscular EMG in healthy young adults, and observed differential activation patterns among the three submental muscles. In some participants, all three of the muscles were activated during hyoid elevation, while in other participants only two of the muscles were activated for the same physiological activity. The authors concluded that there was no consistent pattern of activation observed among the three muscles during hyoid elevation in normal subjects.

**The Tongue**

The tongue is a “muscular hydrostat” capable of accurate and rapid changes in movement to perform swallowing and speech tasks (Sawczuk & Mosier, 2001, p. 19). Kier and Smith (1985) defined a muscular hydrostat as a muscular structure that does not have skeletal support, yet produces a variety of complex movements. One of the characteristic features of a muscular hydrostat, such as the human tongue, is that it maintains constant volume. Thus, a change in any one dimension of the muscular hydrostat is compensated by changes in another dimension (Kier & Smith, 1985).
The importance and role of the tongue in the oral and pharyngeal stages of swallowing is highlighted by previous research (Youmans, Youmans, & Stierwalt, 2009). The tongue is involved in bolus manipulation and transport, and plays an important role during both the oral and pharyngeal stages of swallowing (Dodds, 1989; Dodds, Stewart, & Logemann, 1990; Youmans & Stierwalt, 2006; Youmans et al., 2009). The tongue is responsible for generating the primary force that propels the bolus through the pharyngeal stage (Ertekin & Aydogdu, 2003). The lingual muscles that constitute the tongue contribute to the speed, precision (Sawczuk & Mosier, 2001), and force with which the tongue moves during oropharyngeal swallowing.

Structurally the tongue is composed of muscles and connective tissue, and is covered with a fibrous capsule (Bosma et al., 1986). Anteriorly, the apical portion of the tongue falls behind the incisors, and posteriorly the tongue is attached to the mandible and the hyoid bone (Drake et al., 2005). The tongue is functionally divided into (a) the tongue tip, (b) the tongue blade, (c) the body, or the mass of the tongue, (d) the dorsum, consisting of the broad surface, and (e) the root of the tongue (Owens, Metz, & Farinella, 2011). All the muscles of the tongue are paired, because the tongue is divided by the median sagittal septum into right and left halves (Drake et al., 2005). The tongue consists of eight muscles, four extrinsic, and four intrinsic muscles.

**Extrinsic muscles of the tongue.** The extrinsic muscles of the tongue originate from various hard tissues and insert into the body of the tongue (Sawczuk & Mosier, 2001; Stal, Marklund, Thornell, DePaul, Eriksson, 2003). The genioglossus, originates from the mandibular symphysis and courses posteriorly, and “. . . makes a substantial
contribution to the structure of the tongue” (Drake et al., 2005, p. 1039). The inferior fibers of this muscle attach to the hyoid, while the remaining fibers of this muscle combine with intrinsic lingual muscle fibers in the dorsum of the tongue (Drake et al., 2005; Miyawaki, 1974). The genioglossus is innervated by cranial nerve XII, the hypoglossal nerve. The contraction of the genioglossus results in the depression of the central region of the tongue, and the protrusion of the anterior tongue (Drake et al., 2005).

The hyoglossus originates from the hyoid and inserts into the body of the tongue, lateral to the genioglossus and geniohyoid (Drake et al., 2005). The hyoglossus is also innervated by the hypoglossal nerve, and on contraction results in tongue depression (Drake et al., 2005). The styloglossus originates from the styloid process of the temporal bone, courses towards the tongue tip, and inserts into the lateral surface of the tongue (Drake et al., 2005; Miyawaki, 1974). Also innervated by the hypoglossal nerve, the styloglossus is responsible for tongue retraction and superior movement of the back of the tongue (Bass & Morrell, 1992; Drake et al., 2005). The palatoglossus originates from the palatine aponeurosis and inserts into the lateral surface of the tongue (Drake et al., 2005). The palatoglossus is innervated by the vagus nerve, and is responsible for the depression of the soft palate and elevation of the back of the tongue (Bass & Morrell, 1992; Drake et al., 2005).

Among the extrinsic muscles, the styloglossus and genioglossus are considered to be “tongue retruders,” while the genioglossus is a “tongue protruder” (Sawczuk & Mosier, 2001, p. 20). The extrinsic muscles are responsible for moving the mass of the
tongue with respect to the position of the mandible and the hyoid bone (Bosma et al., 1986).

**Intrinsic muscles of the tongue.** The intrinsic muscles of the tongue are not attached to an external structure. These muscles are responsible for producing precise lingual movements, such as changing the length of the tongue, curling the tongue apex and edges, flattening the tongue surface (Drake et al., 2005; Sawczuk & Mosier, 2001), and changing the shape of a specific part of the tongue (Bosma et al., 1986). The body of the tongue is composed of intrinsic muscles that have parallel and perpendicular courses to the long axis of the tongue (Stal et al., 2003). The tongue consists of four intrinsic muscles.

The superior longitudinal muscle originates from the connective tissue at the back of the tongue and from the median septum, and inserts into the margins of the tongue (Drake et al., 2005). Contraction of this muscle results in shortening the tongue and curling the tongue apex and sides resulting in a trough shaped formation (Owens et al., 2011). The inferior longitudinal muscle, situated between the genioglossus and the hyoglossus, originates from the root of the tongue to insert into the apex of the tongue. This muscle is responsible for shortening the tongue, uncurling the tongue, and the downward movement of the apex of the tongue (Drake et al., 2005; Owens et al., 2011). The longitudinal muscle fibers are arranged parallel to the long axis (Kier & Smith, 1985). The transverse muscle courses from the median septum into the lateral margins of the tongue, and is responsible for narrowing and elongating the tongue (Drake et al., 2005; Kier & Smith, 1985). The transverse muscle fibers are arranged perpendicular to
the long axis. The vertical muscle originates from the tongue dorsum, inserts into the ventral portion of the tongue, and is responsible for flattening and widening the tongue (Drake et al., 2005). The transverse muscle constitutes the majority of the tongue root (Kier & Smith, 1985), whereas the vertical muscle is concentrated in the superior portion of the tongue (Miyawaki, 1974). The simultaneous contraction of the transverse and longitudinal muscles results in bending of the tongue (Kier & Smith, 1985). The hypoglossal nerve innervates all the intrinsic muscles of the tongue. Figure 3 illustrates the extrinsic and intrinsic muscles of the tongue.

Figure 3. The extrinsic and intrinsic muscles of the tongue. This figure was published in Gray’s Anatomy for Students (2nd ed.), by R. L. Drake, A. W. Vogl, and A. W. M. Mitchell, 2010, p. 1038. Copyright 2010 by Elsevier. Reprinted with permission.
Coordination between the extrinsic and intrinsic lingual muscles for lingual movements. In order to better understand the extent of coordination between the extrinsic and intrinsic lingual muscles, let us take into consideration the muscle activity required for one lingual movement: lingual protrusion. In accordance with the muscular hydrostat theory (Smith & Kier, 1989), lingual protrusion results from the contraction of intrinsic lingual muscles (vertical and transverse muscles) that results in the narrowing of the tongue, and the genioglossus that results in the forward movement of the tongue (Pittman & Bailey, 2009). Activation of the genioglossus, vertical, and transverse muscles, categorized as tongue protruders, were observed during impeded and unimpeded tongue protrusion tasks. Unimpeded lingual protrusion resulted in isotonic contractions, whereas impeded lingual protrusion resulted in isometric contractions of the muscles participating in the task (Pittman & Bailey, 2009). However, the authors noted greater activation of intrinsic lingual muscles during impeded lingual protrusion conditions when compared to unimpeded lingual protrusion beyond the teeth (Pittman & Bailey, 2009).

When assessing the contributions from the lingual muscles for protrusion conditions, it is expected that the two intrinsic muscles constituting the anterior portion of the tongue generate protrusive forces, while the genioglossus contributes to changing the tongue position and maintaining stabilization (Pittman & Bailey, 2009). Pittman and Bailey (2009) also reported that the forward movement of the tongue tip is achieved by the sole contraction of the genioglossus. However, in order to result in the protrusion of the entire tongue, the combined activity of the intrinsic protruder muscles and the genioglossus are required (Pittman & Bailey, 2009).
Lingual movements in swallowing. Lingual movements are responsible for formation and control of the bolus, as well as bolus propulsion through the oral cavity during swallowing (Clark et al., 2003). The continued “rotary lateral movement” of the tongue is responsible for placing the food on the teeth, and formation of the bolus (Logemann, 1998, p. 25). The anterior-superior tongue movement helps in positioning the bolus on the tongue surface (Chi-Fishman, Stone, & McCall, 1998). The contraction of the genioglossus, hyoglossus, vertical, and transverse muscles are responsible for the formation of the grooved depression on the surface of the tongue dorsum during swallowing. This pattern of muscle deformation was quantified by magnetic resonance imaging of dry swallows in healthy participants by Napadow, Cgen, Wedeen, and Gilbert (1999). This central groove, and the anchoring of the tongue margins and tip against the hard palate facilitates the posterior movement of the bolus (Logemann, 1998). Although all the lingual muscles contribute to the formation and propulsion of the bolus during oropharyngeal swallowing, the styloglossus and the genioglossus have been identified as the muscles that are most likely to be activated first (Sawczuk & Mosier, 2001). Such lingual movements are not only controlled by the cortical areas of the primary motor cortex, but also by sensory input, input from subcortical areas, and the hypoglossal nucleus (Sawczuk & Mosier, 2001). The propulsion of the bolus in the oral cavity is achieved as the tongue tip contacts the hard palate, along with the maximum elevation of the middle and posterior parts of the tongue (Chi-Fishman et al., 1998), and is referred to as the “stripping action” (Logemann, 1998, p. 27).
Lingual pressure influences bolus clearance and bolus propulsion through the oral and pharyngeal stages of swallowing (Robbins et al., 1995). The lingual swallowing pressure depends on the viscosity of the food or liquid, and increases with an increase in viscosity (Dantas & Dodds, 1990; Logemann 1998). Normal lingual function is required for bolus control and movement during the oral phase and contributes to the pharyngeal phase of swallowing. The primary force that propels the bolus through the pharyngeal stage is the posterior propulsive movement of the tongue (Ertekin & Aydogdu, 2003). Contraction of the intrinsic and extrinsic muscles of the tongue, in addition to the stabilizing effect of the suprahyoid muscles, contribute to functional lingual movements observed in speech and swallowing (Clark, 2012; Palmer et al., 2008).

Based on our understanding of normal lingual functioning required for oropharyngeal swallowing, variations and impairments in lingual muscle structure and function could result in dysphagia. Manifestations of impaired lingual function would include difficulties in mastication, incomplete bolus formation, difficulties in bolus positioning, increased residue, impairments in oral and pharyngeal bolus transit, and premature spillage (Logemann, 1998; Stierwalt & Youmans, 2007; Youmans & Steirwalt, 2006). Specifically, impaired lingual function such as (a) tongue thrust results in difficulty holding and positioning the bolus on the tongue, (b) impaired lingual control results in difficulty controlling the bolus, and hence “premature loss” of the bolus into the pharynx, (c) impaired lingual coordination and incomplete tongue-to-palate contact results in a fragmented bolus in the oral cavity, and (d) reduced tongue strength and hence reduced lingual pressure, results in increased residue in the oral cavity and
difficulties in the formation and control of the bolus, thereby oral and pharyngeal dysphagia (Logemann, 1998).

**Muscle Fibers in Lingual and Submental Musculature**

Based on the speed of contraction, resistance to fatigue, and histochemical properties, muscle fibers can be classified as Type I, Type IIA, and Type IIB (Cooper & Perlman, 1997). Type I muscles are slow twitch fibers that are fatigue resistant, have oxidative metabolism, and are smaller relative to the Type II fibers (Clark et al., 2003). Type I fibers are recruited first for generating small forces. Type II fibers are further classified as either fast fatigable, fibers that are more prone to fatigue, and fast resistant fibers, fibers that are less prone to fatigue (Clark et al., 2003). Type IIA fibers are fast twitch fibers that are fatigue resistant, and have oxidative-glycolytic metabolism. Type IIB fibers are also fast twitch fibers, but are susceptible to fatigue and have glycolytic metabolism (Cooper & Perlman, 1997). Characteristics of muscles, such as each muscle’s cross-sectional area, determine the force production capability of the muscle (Korfage, Schueler, Brugman, Eijden, 2001).

Based on a cadaver study, it was determined that the submental musculature is primarily made up of Type IIA fibers (Korfage et al., 2001). The contraction of these muscles is phasic in nature (Korfage et al., 2001; Palmer, 1989). The muscle fibers that constitute the majority of the tongue are Type II fibers, specifically Type IIA (Stal et al., 2003). There is a large concentration of Type II fibers in the anterior and middle portions of the tongue. In contrast, the posterior tongue has relatively fewer Type II fibers (Stal et al., 2003). Among the intrinsic lingual muscles, the vertical muscle consists of more Type
II fibers when compared to the longitudinal and the transverse muscles. A high proportion of Type I fibers are present in the middle and posterior portion of the longitudinal muscle. The tongue tip consists of a high concentration of both type IIA and IIAB fibers, which contribute to the quick changes in tongue tip position required for speech movements (Stal et al., 2003). The diameter of the muscle fibers constituting the tongue tip is reduced when compared to those constituting the posterior portions of the tongue, which in turn corresponds to the force production capability (Stal et al., 2003). The muscle fibers that constitute the anterior tongue are Type II fibers. Such fibers on contraction result in greater generation of pressure in comparison to Type I fibers (Gingrich, Stierwalt, Hageman, & LaPointe, 2012).

The differences in distribution of muscle fibers throughout the tongue reflect the nature of tasks and contraction patterns undertaken by the different parts of the tongue during functions such as swallowing and speech (Stal et al., 2003). Clark et al. (2003) provides an example of the complex interaction patterns among the lingual muscles during speech and swallowing tasks: During elevation of the tongue tip, it is most probable that certain lingual muscles are involved in isometric contraction, while other lingual muscles are involved in isotonic contraction.

**Electromyography and Submental Muscle Activation**

EMG is a method used to record and monitor the sequential activity of the muscles involved in oropharyngeal swallowing (Ertekin & Aydogdu, 2003). EMG represents and quantifies electrical activity generated from muscular contraction (Crary & Groher, 2000). To better understand an EMG signal, it is important to define the concept
of the motor unit (Palmer, 1989; Perlman, 1993). The motor unit consists of the cell body and axon of a lower motor neuron, the neuromuscular junction, and the muscle fibers that are innervated by that specific neuron (Palmer 1989). Activation of the lower motor neuron results in (a) depolarization of the neuron, (b) activation of the neuromuscular junction resulting in the release of neurotransmitters, and (c) generation of an action potential (Palmer, 1989). Contraction of the muscle fibers occurs as a result of the release of calcium ions secondary to the action potential. These contracted muscle fibers generate an electrical signal, which is measured using EMG (Palmer, 1989; Perlman, 1993). The strength of contraction depends on factors such as the number of contracting muscle fibers and the distance between the electrode and the motor unit. A greater distance between the source and the electrode of the EMG signal decreases the amplitude of the signal (Stepp, 2012). The amplitude of the EMG signal also depends on the presence of volume conductors. Stepp (2012) defines volume conductors as tissues that separate the source and the electrode, and can include muscles, fat, and skin. It has been established that EMG is considered to be an “effective technique” for understanding the properties of different musculature involved in the swallowing mechanism (Perlman, 1993, p. 354).

The electrical activity from contraction of superficial muscles is recorded using sEMG. Thus, the submental musculature is usually targeted (Huckabee et al., 2005). Also, as sEMG enables muscle activity from a larger area to be recorded, it is specifically used to record activity of subcutaneous muscles (Palmer et al., 1999). Used extensively in swallowing research, sEMG is considered a reliable and simple method for both evaluation and feedback (Crary & Baldwin, 1997; Palmer 1989; Vaiman et al., 2004b).
Ertekin and Aydogdu (2003) concluded that using surface electrodes to record the activity of a few important muscles would be more logical than recording activity from many muscles constituting the swallowing musculature. The authors also stated that detecting and recording sEMG activity from the submental muscles is an easy task when compared to recording the same from other muscles involved in the swallowing mechanism. As an objective method of documenting “composite activity” of underlying muscles, sEMG detects activity even when one of the muscles in the group is active (Ding, Larson, Logemann, & Rademaker, 2002, p. 1).

Palmer et al. (1999) simultaneously recorded intramuscular and surface EMG from the submental muscles to determine the contributions of individual muscles to submental sEMG. They established that the mylohyoid, geniohyoid, and the anterior belly of the digastric were the primary contributors to submental sEMG recordings. Based on correlation analysis, the greatest positive relationship was observed between the mylohyoid and submental sEMG for the majority of participants (Palmer et al., 1999). They also determined that contributions from the platysma and genioglossus were minimal to the submental sEMG measurements (Palmer et al., 1999). However, changes in bolus characteristics such as viscosity were observed to result in significant changes in the nature of contribution from the submental muscles to sEMG measures (Palmer et al., 1999).

Based on intramuscular EMG recordings of the muscles during saliva swallows, mean firing order of the submental muscles and genioglossus was established to be: geniohyoid, followed by mylohyoid and genioglossus, and lastly, anterior belly of the
digastric (Hrycyshyn & Basmajian, 1972). Intersubject variability in submental sEMG recordings were attributed to differences in the “temporal firing pattern” of the muscles that form the floor of the mouth (Palmer et al., 1999, p. 1388). However, sEMG is frequently used to examine submental muscle activation in swallowing research (Crary, Carnaby, & Groher, 2006; Ding et al., 2002; Huckabee & Steele, 2006; Wheeler-Hegland, Rosenbek, & Sapienza, 2008; Vaiman et al., 2004b).

The components required for sEMG recording include the surface electrodes, electrode cable, and the master unit (Crary & Groher, 2000). The surface electrodes adhere to the skin and connect to the master unit via the electrode cable. The master unit consists of various components such as the amplifier, filter, and displays for visual feedback (Crary & Groher, 2000). The sEMG resting potential of the submental muscles was reported to be 2.808 ± 2.21 µV, which reflects not only the electric tension from the relaxed muscles, but also skin resistance (Vaiman et al., 2004b).

The sEMG approach is useful in quantifying muscle activation patterns using measures such as the amplitude and duration of activation from a group of muscles during a functional activity (Crary & Groher, 2000; Perlman et al., 1999). Additionally, sEMG is a useful feedback tool (Bryant, 1991; Crary & Groher, 2000), because it provides patients with a visual and quantitative display of muscle properties such as strength and timing of muscle contraction (Huckabee et al., 2005). When describing the amplitude of sEMG during dry and effortful swallows, investigators should report the range of values (minimum and maximum), because swallow trials tend to differ in duration. Hence, reporting the range of values is of more clinical importance than the
mean (Vaiman et al., 2004b). Vaiman et al. (2004b) suggests that reporting the mean value during sEMG would be more relevant if trials of the same duration are being compared. In addition, the values generated by the instrument are not representative of the true mean or range of sEMG activity, because the baseline or resting potential has not been deducted from the instrument-generated values (Vaiman et al., 2004b).

**Lingual Strength Measurements**

Lingual strength can be measured subjectively and objectively. Subjective assessments of estimating lingual strength are most often used clinically. An example of subjective assessment of lingual strength would be to judge and rate the lingual pressure exerted by an individual to the external resistance offered by the clinician or examiner during lingual protrusion or lateralization (Clark et al., 2003). A major disadvantage of subjective assessments of lingual strength is the lack of reliability and consistency among examiners (Youmans & Steirwalt, 2006). Objective methods that detect reduced tongue force are predictive of oral dysphagia (Clark et al., 2003).

Values that objectively reflect lingual strength include peak swallowing pressure, peak lingual pressure during maximum isometric lingual conditions, and percentage of maximum tongue pressure (Clark et al., 2003; Robbins et al., 2005; Youmans & Stierwalt, 2006). Instruments that have been used to quantify lingual pressure during isometric and swallowing tasks include, but are not limited to the Iowa Oral Pressure Instrument (IOPI) (Clark et al., 2003; Clark & Solomon, 2012; Gingrich et al., 2012; Lazarus, Logemann, Huang, & Rademaker, 2003; Robbins et al., 1995, 2005), the three-bulb tongue array by Kay Elemetrics (Lenius, Carnaby-Mann, & Crary, 2009; Nicosia et
al., 2000; Robbins et al., 2005, 2007), the Tongue Force Measurement System (Robinovitch, Hershler, & Romilly, 1991), and the T-shaped sensor sheet (Hori, Ono, Nokubi, Kumakura, 2005). Using the three-bulb tongue array to record lingual pressure may be preferable to the IOPI, especially when simultaneously recording pressures exerted by multiple tongue sites (anterior, middle, and posterior), as re-positioning of the array is not required (Gingrich et al., 2012).

Peak pressure during nonswallowing maximum isometric postures of the tongue is a measure that has been adopted frequently in research as a function of maximum lingual strength (Clark 2012; Clark et al., 2003; Lazarus et al., 2003; Robbins et al., 1995, 2005; Youmans & Stierwalt, 2006). Maximum isometric lingual pressure recorded from lingual conditions involving tongue tip elevation and protrusion represents an individual’s maximum anterior tongue strength in each direction (Youmans & Stierwalt, 2006). The procedure for recording pressure during maximum isometric lingual conditions involves having the individual exert maximum lingual effort against the measuring device for a period of time in a specific direction (Youmans & Stierwalt, 2006). The isometric condition involves a static posture of the tongue against resistance in which the investigator can measure the amplitude of contraction of lingual muscles, free of changes in muscle length (McArdle, Katch, & Katch, 2006). Among the many measures of lingual strength during isometric lingual conditions, reporting the maximum or peak value of the pressure generated among the trials seems to be the most commonly used (Clark et al., 2003; Lazarus et al., 2003; Robbins et al., 1995). This measure represents the maximum pressure an individual is capable of producing (Clark et al.,
Another method of reporting lingual strength is to calculate the average of peak pressures generated across the trials (Robinovitch et al., 1991). Calculating the average of the maximum isometric pressures would be indicative of the participant’s typical performance (Clark et al., 2003). Clark et al. (2003) compared the two measures to assess whether one measure was a better representative of tongue strength than the other and determined that there was no distinct advantage of using one measure over the other as both were similar representations of tongue strength.

Lingual swallowing pressure is measured during saliva or dry swallows, or during bolus swallows. Maximum lingual pressure during saliva and bolus swallows is submaximal when compared to that generated during maximum isometric lingual conditions (Gingrich et al., 2012). Measurement of lingual swallowing pressure is more likely to provide a functional index of muscle strength (Youmans & Steirwalt, 2006).

**Submental Muscle Activation During Lingual Functions**

Multiple regression analysis revealed that among the submental muscles, muscles of the tongue and velum, greatest relationships were observed between the submental or floor-of-mouth muscles (namely the mylohyoid, geniohyoid, and anterior belly of the digastric), and the genioglossus for increased tongue pressures recorded during tongue-to-palate contact (Palmer et al., 2008). Based on such an observation, Palmer et al. (2008) hypothesized that increased submental muscle strength resulting from such lingual exercises will be reflected in oropharyngeal swallowing as improvements in mastication, laryngeal excursion, and transfer of the bolus through the oral stage of swallowing.
It has been recognized that sEMG measures from the submentum area represents activity from not only the muscles that form the suprahyoid musculature, but also certain extrinsic lingual muscles, such as the genioglossus, and intrinsic lingual muscles (Huckabee et al., 2005; Huckabee & Steele, 2006; Sonies, Stone, & Shawker, 1984). This was also supported by Palmer et al. (1999), based on the finding that submental sEMG represents electrical activity from the submental muscles, and also consists of contributions from the platysma and the genioglossus, based on the proximity of muscle location to the electrode site. Sonies et al. (1984) suggested that early contraction of the submental muscles in conjunction with that of the extrinsic lingual muscles provides a base that offers support for the generation of lingual propulsive forces during the oral swallow.

**Effects of Age on Submental Muscle Activation and Lingual Strength**

Sarcopenia refers to the loss of skeletal muscle mass and strength related to aging (Evans, 1995; Yeates, Molfenter, & Steele, 2008). Structural changes in muscles secondary to aging may include a reduction in the size and number of muscle fibers (Campbell, McComas, & Petito, 1973). Another change to the muscle fibers associated with aging is the enlargement of motor units with reduction in the concentration of fast-twitch fibers (Ekberg & Feinberg, 1991). Neurologically normal individuals above the age of 65 years have been observed to exhibit differences in swallowing function such as delayed initiation of laryngeal and pharyngeal events (Robbins, 2003). Ekberg and Feinberg (1991) assessed the swallowing function in elderly individuals ranging in age from 72 to 93 years, and noted that changes in the oral stage of swallowing, such as
difficulties with bolus intake and control, were commonly observed in this age group. It is especially important to quantify such age-related changes in submental and lingual muscle function during swallowing and during lingual conditions, given that the previously mentioned changes during the oral stage of swallowing were observed in healthy older adults without any previous history of swallowing impairments (Ekberg & Feinberg, 1991).

**Effects of age on submental muscle activation as measured by sEMG.**

Healthy subjects above the age of 70 years were observed to exhibit greater durations of submental sEMG activity for dry and bolus swallows (Vaiman et al., 2004b). Young subjects between the ages of 18 to 30 years exhibited significantly higher amplitudes of submental sEMG when compared to elderly healthy subjects above the age of 70 years (Vaiman et al., 2004b). For saliva swallows, normative values of submental sEMG ranged from 13.4 to 59.72 µV in healthy subjects below 30 years of age, 9.52 to 49.5 µV in healthy subjects between the ages of 31 and 70 years, and 10.2 to 42.32 µV in healthy subjects above 70 years of age. The ranges for submental muscle activity were observed to be higher than other muscle groups, such as the infrahyoid and masseter (Vaiman et al., 2004b).

**Effects of age on lingual strength as measured by lingual pressures.**

Lingual tissues in individuals above the age of 60 years have been associated with increased fatty and connective tissue content (Robbins, 2003). Atrophy of the lingual muscles can affect lingual functions (Urago, 1991). Reduced lingual strength in elderly individuals has been attributed to age-related changes such as reduced lingual muscle
mass, which in turn may influence swallowing functions (Robbins 2003; Robbins et al., 1995). Additionally, older individuals have been shown to exhibit reduced tongue mobility, suction pressure (Sonies et al., 1984), and decreased pressure during tongue to palate contact (Shaker, Dodds, Hogan, & Stemper, 1990). Oral dysphagia, secondary to lingual weakness, may manifest as reduced bolus propulsion through the oral and pharyngeal cavity, increased residue, and decreased mastication in patients with neurogenic disorders (Logemann, 1998). Youmans et al. (2009) recognized the importance of identifying reduced tongue strength reserve, especially in those who exhibit or who are at risk for dysphagia secondary to reduced lingual strength. The following sections summarize findings from research that has examined the effects of age on lingual pressure generation during isometric lingual conditions and during swallowing in healthy adult participants.

Robbins et al. (1995) measured lingual pressures from three tongue sites (anterior, middle, and dorsum of the tongue) in young and older subjects using the IOPI. Older subjects (> 60 years) exhibited reduced maximum isometric tongue pressures than the younger and middle-aged groups. Reduced maximum isometric lingual pressures were observed particularly at the tongue blade in older subjects (Robbins et al., 1995). Although maximum lingual pressures during isometric conditions were found to be different between younger and older healthy subjects, similar peak swallowing pressures were recorded for both groups. As peak pressures in swallowing are submaximal when compared to the maximum isometric pressures, the older subjects were able to generate adequate swallowing pressures (Robbins et al., 1995). However, the percentage of
maximum pressure used during swallowing was greater for the older group, indicative of reduced “pressure reserve” (Robbins et al., 1995, p. M260).

Robbins et al. (1995, p. M261) suggested that the “slowed swallowing” in older individuals may serve as a compensatory strategy. Slower swallowing would allow the older individual greater time to generate the required swallowing pressures necessary to propel and clear the bolus during oropharyngeal swallowing (Robbins et al., 1995). With increasing age, individuals may also be required to expend more effort in order to generate lingual pressures required for an effective swallow (Robbins et al., 1995).

Youmans et al. (2009) also observed that maximum isometric lingual pressure decreased with age, but mean lingual pressure during swallowing did not. Such decreased lingual pressures during such maximum isometric lingual conditions reflect the effects of aging on body musculature (Crow & Ship, 1996; Youmans & Steirwalt, 2006; Youmans et al., 2009).

Older subjects were observed to exhibit significantly reduced tongue protrusion ($M = 58$ kPa) and lateralization ($M = 45.2$ kPa) pressures, when compared to young and middle-aged healthy subjects (Clark & Solomon, 2012). Mean tongue protrusion pressure was recorded to be 69.7 kPa and 58 kPa in young and elderly healthy subjects, respectively (Clark & Solomon, 2012). Older individuals also exhibited reduced posterior tongue elevation pressures ($M = 47.4$ kPa) when compared to the middle-aged group, ($M = 57.9$ kPa). Highest pressures in anterior tongue elevation were recorded from the healthy middle-aged subjects (30 to 59 years; $M = 62.8$ kPa), followed by younger subjects (18 to 29 years), and then the older subjects (60 to 89 years). However, no
significant difference in anterior tongue strength during elevation was observed between the younger \((M = 55.8 \text{ kPa})\) and the older groups \((M = 51 \text{ kPa};\) Clark & Solomon, 2012). Maximum isometric lingual pressures were recorded to be higher in young individuals than those above the age of 69 years (Nicosia et al., 2000). Reduced lingual strength among the older individuals was attributed to age-related changes in skeletal muscle strength. Similar findings were reported by Youmans and Stierwalt (2006); maximum isometric lingual pressures in individuals above the age of 60 years \((M = 54.5 \text{ kPa})\) was found to be significantly less than that observed in young individuals between the ages of 20 and 39 years \((M = 63.9 \text{ kPa};\) Youmans & Steirwalt, 2006). However, the mean swallowing pressures were found to be similar between the two groups (Nicosia et al., 2000; Youmans & Stierwalt, 2006).

**Effects of Gender on Submental Muscle Activation and Lingual Strength**

**Effects of gender on submental muscle activation as measured by sEMG.**

There has been limited research examining the effects of gender of submental sEMG measurements. However, Vaiman, Eviatar, and Segal (2004a) reported no significant differences in the duration of sEMG muscle activity between men and women.

**Effects of gender on lingual strength as measured by lingual pressures.**

Men were found to exhibit greater anterior maximum isometric lingual pressure than women (Gingrich et al., 2012), which was attributed to the greater biological strength in males than females. Youmans and Steirwalt (2006) also examined lingual strength during swallowing and during lingual isometric tasks in healthy subjects varying in age from 20 to 79 years using an IOPI. They determined that the maximum isometric tongue pressure
was found to be significantly higher in males ($M = 64$ kPa) than in females ($M = 55.9$ kPa), which was also attributed to the higher strength capabilities in males (Youmans & Steirwalt, 2006). Maximum tongue strength in males was also reported to be greater than that in females by Mortimore, Fiddes, Stephens, and Douglas (1999) and by Stierwalt and Youmans (2007).

Although statistically significant differences were not observed, Youmans et al. (2009) reported slightly higher mean maximum isometric tongue pressures in older men ($M = 62.60$ kPa) when compared to older women ($M = 57.56$ kPa). Similar observations were observed in lingual pressures between that of younger men and women ($M = 77.63$ kPa and $M = 73.25$ kPa, respectively; Youmans et al., 2009). Clark and Solomon (2012) observed similar tongue strength measures between the male and female participants in their study. However, Gingrich et al. (2012) observed higher mean pressures in females than in males. The authors hypothesized that the smaller oral cavities in females would result in the generation of greater lingual pressures. Also, the presence of a lingual bulb in the oral cavity would offer greater resistance to the flow of the bolus (Gingrich et al., 2012). No significant differences were observed in lingual swallowing pressures between men and women (Gingrich et al., 2012; Nicosia et al., 2000; Youmans & Stierwalt, 2006).

**Lingual Exercises and Maneuvers in Dysphagia Treatment**

An overview of therapy techniques adopted in dysphagia treatment known to influence submental muscle and lingual functioning are discussed in the following sections.
**Repeated effortful swallow.** The effortful swallow, a compensatory swallow maneuver, is designed to increase tongue pressure and tongue base movement (Pouderoux & Kahrilas, 1995). This strategy, when repeated, is expected to increase the amplitude and duration of hyoid excursion, and duration of submental muscle activity (Hind, Nicosia, Roecker, Carnes, & Robbins, 2001; Huckabee et al., 2005; Wheeler-Hegland et al., 2008). Yeates, Steele, and Pelletier (2010, p. 279) also suggest, “tongue-palate pressure is particularly important in generating effortful swallow.”

Effortful swallows are found to result in higher peak submental sEMG in healthy adult participants, when compared to that recorded during thin liquid swallows (Wheeler-Hegland et al., 2008). Yeates et al. (2010) observed greater amplitudes of submental sEMG measures and intraoral lingual pressures during effortful swallows, when compared to noneffortful swallows in healthy women. Huckabee and Steele (2006) also recorded higher amplitudes during submental sEMG and higher orolingual pressures during effortful swallow maneuvers with tongue to palate emphasis. The authors suggested that the effortful swallow with emphasis on lingual palatal contact could be used as type of “motor system priming,” because such an exercise increases motor system performance (Huckabee & Steele, 2006, p. 1071). The submental sEMG and lingual pressures obtained during an effortful wallow trial might represent the “maximal voluntary contraction” (Stepp, 2012, p. 1236) of the lingual and submental musculature. These values might serve as a reference against which comparisons of submental muscle activity during isometric lingual conditions may be made.
**Lingual strengthening exercises.** Lingual strengthening exercises are gaining popularity among clinicians in the treatment of patients with dysphagia. Such active exercises are considered to have a positive influence on muscle strength, with the aim of reversing decrements in muscle strength with age (Robbins, 2003). Exercise programs, both strength and endurance training, have been shown to result in increased muscle strength by reducing the concentration of Type IIB fibers, which are prone to fatigue, and by increasing Type IIA fibers (Fitts, 2003). Specifically, tongue exercises, which involve resistance training, are thought to result in improved characteristics of bolus flow. These exercises have been shown to increase lingual pressures in older healthy individuals and in stroke patients (Robbins et al., 2005, 2007).

Strength training, usually adopted in instances of muscle weakness, can utilize isometric or isotonic exercises depending on the nature of muscle contraction (Neumann, Bartolome, Buchholz, & Prosiegel, 1995; Ruscello, 1995). During isotonic lingual exercises, the muscle tone remains constant. An example of an isotonic lingual exercise is when the tongue moves against resistance, such as using the tongue tip to push a tongue depressor away from the mouth (Neumann et al., 1995). During isometric lingual exercises, the length of the muscle fibers remain constant while force is generated, such as when the tongue maintains position against resistance (Fitts, 2003; Neumann et al., 1995). An example of an isometric lingual exercise would be maintaining the tongue tip in midline position when lateral external pressure is applied using a tongue depressor (Neumann et al., 1995).
Peak isometric lingual and swallowing pressures in healthy older individuals were observed to increase following eight weeks of a progressive lingual resistance exercise protocol (Robbins et al., 2005). These observations support the fact that the lingual weakness observed secondary to aging can be reversed with exercise. In older individuals, such exercises may serve to increase the “functional reserve capacity” (the difference between peak lingual pressures during maximum isometric lingual postures and during swallowing) “prior to illness or trauma,” especially considering that these individuals are at an increased risk for developing dysphagia (Robbins et al., 1995, p. M261). Lazarus et al. (2003) also reported increased mean peak lingual pressures in young individuals ranging in age from 20 to 29 years following tongue strengthening exercises with either an IOPI or a tongue depressor. The clinical implications of the findings by Robbins et al. (2005) and Lazarus et al. (2003) is important given the impact of strength training on swallowing musculature, especially considering the potential applications in preventive and rehabilitative exercise programs.

Significantly, higher mean and maximum submental sEMG was recorded following isotonic tongue press exercises when compared to isotonic head lift exercises in normal adults, which suggests that such tongue exercises would be beneficial in strengthening the submental musculature (Yoshida, Groher, Crary, Mann, & Akagawa, 2007). Such lingual exercises would be preferred over other exercises targeting the same group of muscles, considering the ease of instruction and execution (Yoshida et al., 2007).
Effects of Lingual Conditions on Lingual Strength and Submental Muscle Activation

Lingual strengthening exercises consist of lingual conditions that involve tongue movements in different directions such as elevation, protrusion, and lateralization. Healthy adults exhibited increased lingual strength following lingual elevation, protrusion, and lateralization exercises (Clark, Brien, Calleja, & Corrie, 2009; Lazarus et al., 2003; Robbins et al., 2005). Lingual exercises involving lingual lateralization and protrusion conditions resulted in greater lingual strength gains than exercises involving lingual elevation (Clark et al., 2009). The authors recommend that for lingual strengthening exercises involving lingual elevation, a less intensive paradigm that does not involve daily exercise should be adopted (Clark et al., 2009).

Clark and Solomon (2012) have also documented orofacial strength in healthy adults varying in age using the IOPI. No significant differences were documented in anterior and posterior tongue elevation, and tongue protrusion pressures between men and women (Clark & Solomon, 2012). Although Clark and Solomon (2012) did not directly examine the differences between these conditions, tongue protrusion resulted in greater maximum lingual pressures than anterior and posterior tongue elevation conditions. Yoshida et al. (2007) recorded peak tongue-to-palate lingual pressures from the anterior bulb for both isotonic and isometric tongue press exercises in healthy adults, and indicated that instructions involving the anterior tongue in lingual strengthening exercises would yield maximum benefits. Exercise involving the generation of tongue-to-palate lingual pressure is considered to be a “promising measure” for objectively quantifying
lingual activity (Hori et al., 2005). However, estimating tongue strength using a combination of lingual conditions, such as lingual elevation, protrusion, and lateralization, is considered to a better estimate of oral dysphagia than when individual conditions are used (Clark et al., 2003).

Palmer et al. (2008) supported the notion that lingual press exercises that involved lingual elevation to the hard palate would have a positive impact on the strength of the submental muscles, and in turn improve swallowing function. Applying these findings to counteract the effects of aging on swallowing musculature, particularly the submental muscles, is especially important when considering the preventive and dual role that such exercises could offer. However, no studies have explored submental muscle activation, as measured by sEMG, during other lingual conditions that can be incorporated in lingual strengthening exercises such as lingual protrusion, depression, or lateralization.

**Research Aims of the Current Study**

Having reviewed relevant findings in literature, the paucity of research that examines and quantifies the activation and interaction of submental muscles during isometric lingual conditions that involve elevation, protrusion, and depression of the anterior tongue, as well as during swallowing conditions has to be acknowledged. Previous research (Pittman & Bailey, 2009) has adopted maximum impeded movements of the tongue, similar to the ones adopted in this study, such as tongue elevation against the hard palate, tongue protrusion against a tongue depressor, and tongue depression against lower incisors for purposes of normalizing EMG measures. Completing these MIP lingual conditions in young and older healthy participants would help in: (a)
describing submental muscle activation during isometric lingual conditions that can be adopted in lingual strengthening exercises, (b) determining whether a specific lingual condition involving the anterior tongue would result in greater activation of the submental muscles, and (c) establishing a baseline for the possibility of a transfer effect, i.e., if significant contributions from the submental muscles are present, then proceeding to determine the effects of lingual strengthening exercises on these muscles.

Improvements in submental muscle functioning will in turn influence aspects of both the oral and pharyngeal stages of swallowing.

The anterior tongue is reported to generate greater pressures during swallowing and isometric conditions, when compared to other regions of the tongue (Gingrich et al., 2012). Thus, adopting lingual conditions that concentrate on this region of the tongue in an effort to better understand the role of submental muscles during such lingual conditions is supported in the light of such findings. Establishing the presence of a “dual effect” of lingual strengthening exercises (improving lingual and submental muscle function) would be pertinent, considering the use of sEMG as feedback in dysphagia treatment. In addition, establishing the effects of age and gender on submental and lingual muscle function, using sEMG and intraoral lingual pressures respectively, during isometric lingual conditions would further add to the body of literature. Determining such effects on these measurements in healthy participants would be the basis on which specialized dysphagia treatments can be developed. Thus, this study aims to (a) describe submental muscle activation during lingual conditions that involve lingual movement in three directions, and during swallowing, and (b) determine the effects of age, gender, and
lingual condition on submental and lingual muscle function in normal populations. The specific research aims are listed below.

**Research aims and hypotheses.**

**Research aim I.** To describe submental muscle activation using surface electromyography (sEMG) and lingual pressures using the three-bulb tongue array in young (18 to 40 years) and older (60 years and above) healthy adults during intraoral MIP lingual conditions involving the movement of the anterior tongue in three directions (tongue tip elevation to the hard palate, tongue protrusion, and tongue depression in the oral cavity) and during swallowing tasks (dry and effortful swallows).

Functional lingual movements such as lingual elevation to the hard palate are known to result in activation of not only the lingual muscles, but also the submental muscles (Palmer et al., 2008). However, there is a lack of research studying submental muscle activation during lingual conditions involving the movement of the anterior tongue in an anterior and inferior direction (lingual protrusion and depression).

**Research aim II.** To determine the effects of age (young and old), gender (male and female), and intraoral MIP lingual conditions (elevation, protrusion, and depression) on submental muscle activation.

- What are the effects of age and gender on submental muscle activation as measured by sEMG?

**H_0:** There will be no difference in submental muscle activation between young and older healthy participants.
\(H_{a1}\): Lower submental muscle activation (i.e., lower submental sEMG amplitude) will be observed in older healthy participants.

\(H_{02}\): There will be no difference in submental muscle activation between men and women.

\(H_{a2}\): Greater submental muscle activation (i.e., higher submental sEMG amplitude) will be observed in male participants.

It is hypothesized that lower submental muscle activation will be observed in the older group secondary to the effects of age on submental muscles. Male participants are hypothesized to exhibit greater submental muscle activation due to the greater biological strength in males. There has been limited literature examining the effects of age and gender on submental muscle activation, as measured by sEMG. Establishing whether reduced submental muscle activation is observed in older healthy adults would help in identifying the need for an exercise paradigm that targets submental muscle activation, thereby reversing the effects of aging in older healthy participants.

- Will there be a differential effect among the three MIP lingual conditions (depression, elevation, and protrusion) on submental muscle activation as measured by sEMG?

\(H_0\): There will be no difference in submental sEMG measures during the three lingual conditions.

\(H_{a}\): There will be a differential effect of the three lingual conditions on submental sEMG measures.
This differential effect can be attributed to the differences in number and contributions of muscles activated for each lingual condition. This study would help in quantifying submental muscle activation during MIP lingual conditions involving intraoral lingual movements in different directions (elevation, protrusion, and depression). Such lingual movements are those that are or can be adopted during lingual strengthening exercises in dysphagia rehabilitation. If there is a differential effect of lingual condition on submental muscle activation, this study would be the first step in deciding which lingual condition(s) should be adopted when designing a lingual exercise paradigm. The following step will be to determine whether such lingual exercises have a significant effect on submental muscle activation (in individuals with reduced submental muscle activation and in patients with dysphagia), in addition to lingual pressures, thereby confirming whether the lingual exercise regimen targets both the submental and lingual muscles. If increased submental muscle activation is observed following lingual exercises in patients with dysphagia, it is important to assess whether improvements are also observed during the oral and pharyngeal stages of swallowing. This is because activation of the submental muscles are particularly important during hyolaryngeal excursion, a physiological event that ensures the safe transfer of the bolus during the pharyngeal stage of swallowing. Establishing norms in healthy young and older participants will provide a basis for comparison for individuals with dysphagia.

**Research aim III.** To determine the effects of age (young and old), gender (male and female), and intraoral MIP lingual conditions (elevation, protrusion, and depression) on lingual strength as measured by lingual pressures.
What are the effects of age and gender on lingual muscle strength as measured by lingual pressures?

\( H_01: \) There will be no difference in lingual pressures between young and older healthy participants.

\( H_a1: \) Higher lingual pressures will be observed in younger healthy participants when compared to older participants.

\( H_02: \) There will be no difference in lingual pressures between men and women.

\( H_a2: \) Higher lingual pressures will be observed in male participants.

The older group is hypothesized to exhibit lower lingual pressures secondary to the effects of aging on lingual muscles, which might affect the force generating capacity of these muscles. Men are hypothesized to exhibit higher lingual pressures, which may be attributed to the greater biological strength in males. Establishing the effects of age and gender on lingual strength, as measured by lingual pressures, will add to the body of literature in this area. Previous research has reported varied results about differences in lingual pressures between men and women. In addition, determining age effects on lingual pressures will help in potentially identifying a value of lingual pressure similar to a “cut-off” score that would indicate reduced lingual strength in individuals.

Will there be a differential effect among the three MIP lingual conditions (depression, elevation, and protrusion) on lingual pressures?

\( H_0: \) There will be no difference in lingual pressures among the three lingual conditions.
**H₀**: There will be a differential effect of the three lingual conditions on lingual pressures.

This differential effect is potentially due to the differences in the number of muscles activated during each lingual condition. Determining the presence of differential effects of lingual conditions on lingual pressures, would add to the body of literature in this area. Predominantly, lingual pressure generated during maximum isometric lingual-palatal elevation condition has been studied. The lingual conditions adopted in this study reflect lingual movements that can be adopted clinically in lingual strengthening exercises.

**Research aim IV.** To determine the relationship between lingual pressures and submental sEMG during the three intraoral MIP lingual conditions.

- What is the correlation between submental sEMG and the lingual pressures generated for each of the three lingual conditions in young men, young women, older men, and older women?

**H₀**: There will be no relationship between submental sEMG and lingual pressures, i.e., the two variables will be independent.

**Hₐ**: There will be a positive linear relationship between submental sEMG and lingual pressures for each of the three lingual conditions.

Previous research (Yoshida et al., 2007) has established a significant positive relationship between lingual pressures generated during intraoral lingual elevation and submental sEMG. However, correlations between lingual pressures generated during other lingual conditions have not been examined. Significant positive correlations
between the two variables are clinically relevant, given the use of sEMG as a biofeedback tool in dysphagia rehabilitation.
Chapter 3: Method

Participants

Fifty-five adults from the local community expressed interest in participating in the study, of whom 49 were included as participants. Six individuals were excluded from the study, because they did not satisfy the inclusion criteria. The 49 participants were divided into two groups based on age. The young age group consisted of 13 men ($M = 24.23$ years) and 12 women ($M = 21.83$ years), ranging in age from 18 to 35 years ($M = 23.08$ years). Twenty-four healthy adults ranging in age from 60 to 83 years constituted the older group, with 12 men ($M = 68.25$ years) and 12 women ($M = 69.46$ years).

All the participants were healthy adults with (a) normal oral structure and function, (b) no history of swallowing impairment (dysphagia), (c) no history of neurologic or head and neck impairments, (d) no history of neck injury that affected their swallowing function, and (e) were nonsmokers or had discontinued smoking for at least five years. Individuals who reported (a) oral sensory deficits, (b) disorders of smell, (c) gastrointestinal disorders that affected swallowing function, and (d) undergoing treatments or taking medication that affected their swallowing function were excluded from the study.

Set-Up of Instrumentation

There were two sets of instruments used in this study: (a) instrumentation to record the submental muscle activity, and (b) instrumentation to record lingual pressures from the participants.
Instrumentation for recording submental muscle activation. The submental muscle activation in these healthy adults was measured using sEMG. The submental sEMG measurements were recorded on the Digital Swallowing Workstation™ (DSW) Model 7200 using triode surface electrodes, displayed in Figure 4. The DSW™ was connected to the electrodes using clips. The electrodes used for this study had three clips: two for connecting the active electrodes and one for connecting the ground electrode (Kay Elemetrics Corp, 2004). The Ag/AgCl electrodes that were used are wet electrodes, as conductive gel was used to improve the conductivity and amplitude of the signal recorded (Kay Elemetrics Corp, 2005; Stepp, 2012). The conductive gel was placed on the surface of the electrodes that contacted the skin. The triode surface electrodes were fastened to the submental region using the adhesive on the electrode patch. Using these electrodes, the activation of submental muscles, namely the anterior belly of the digastric, mylohyoid, and geniohyoid (Vaiman et al., 2004b), were recorded in µV. Each surface electrode was disposed after a single use.

The DSW™ detected, amplified, and rectified the electrical voltages, and the resulting images were displayed on the monitor of the workstation. The rectified sEMG image consisted of only the positive polarity, to facilitate easy understanding and interpretation of the sEMG measures (Kay Elemetrics Corp, 2004). For sEMG, the DSW™ used a common mode rejection ratio of 100dB and a bandwidth of 50 to 250 Hz (Kay Elemetrics Corp, 2005). A sampling rate of 1000 Hz was used for this study.
Figure 4. The three clips and surface electrode used for measuring submental sEMG.

Instrumentation for recording lingual pressures. Lingual pressures were recorded in mmHg, using a three-bulb array from KayElemetrics®. The array consisted of three air-filled bulbs connected to a metal spine. The anterior, middle, and posterior bulbs recorded lingual pressures from the tip, middle, and posterior parts of the tongue, respectively, during swallow trials. Each of the three air-filled bulbs are 13 mm in diameter, and are placed on a silica strip 8 mm apart (Robbins et al., 2005). The silica strip is attached to a stainless steel “spine,” which extended for 12 cm. Thin tubing emerges from each of the air-filled bulbs and attaches to the connector, which is plugged
into the box that constitutes the hardware module (Kay Elemetrics Corp, 2004). The hardware module was in turn connected to the DSW™.

Prior to recording lingual pressures, the bulbs were inflated and calibrated. When the tongue bulbs were inflated, air was filled at 1.5 to 2 PSI, and the maximum flow rate was 100 ml/minute (Kay Elemetrics Corp, 2005). Graphical displays of lingual pressure recorded from each of the three-bulbs were displayed on the monitor of the DSW™. For recording lingual pressures, a sampling rate of 1000 Hz was used.

The tongue bulb arrays could be re-used for the same participant after cleaning with a mild detergent and warm water (Kay Elemetrics Corp, 2004). Prior to and after use, the tongue bulbs were cleaned with Listerine Antiseptic Mouthwash. Each tongue bulb array was immersed in a bowl containing the antiseptic mouthwash for five minutes, after which it was cleaned thoroughly with warm water. After the tongue bulb array dried completely, it was placed in a sealed zip lock bag with the participant number clearly printed on the bag to facilitate hygienic storage and identification. Figure 5 displays the three-bulb tongue array used for the study.
Procedure

This section describes the protocol followed to record measurements reflecting submental muscle activation and lingual strength from the participants during swallowing, and during lingual conditions. The sequence in which the protocol is described represents the order of events that were followed for each participant. The following section includes participant screening, positioning and placement of instrumentation, and the experimental protocol. Each participant required approximately one hour to complete the protocol described below.

**Participant screening.** After receiving informed consent, a brief demographic and screening questionnaire, and an oral motor examination were completed to ensure that the participants satisfied the inclusionary criteria. The questionnaire was designed to collect additional demographic information and to confirm general health and swallowing function. All the participants reported no previous history of dysphagia or neurologic
disease. Majority of the participants in the older group reported taking medications for conditions such as high blood pressure, cholesterol, and arthritis. No significant medical condition that affected an individual’s swallowing function was reported.

An oral motor (Logemann, 1998) and neurological examination was conducted to document the structure and function of the anatomical areas associated with swallowing, and to assess cranial nerve function. Four participants reported using upper permanent bridges that did not interfere with the placement of the tongue bulb array. All the participants were able to complete the oral motor examination tasks, which were designed to assess labial, lingual, palatal, and laryngeal range of movement and function. Normal swallowing function was confirmed by having the participants swallow trial (5 ml) quantities of thin liquid (water). In particular, the participants were asked about oral sensitivity to ensure that the placement of the three-bulb tongue array would not cause any pain or discomfort. Although torus palatinus was reported by and observed in an older participant, the placement of the tongue array did not result in any discomfort or pain, and the participant was able to complete all the tasks in the experimental protocol with ease. The demographic and screening questionnaire and the oral motor examination are provided in Appendix A and B, respectively.

**Placement of submental sEMG electrode.** Each participant was instructed to sit upright, facing the examiner. Prior to attaching the surface electrodes, the skin beneath the chin was cleaned with an alcohol swab to reduce impedance. The sEMG electrode was positioned on the submental area between the chin and the hyoid bone (Crary & Groher, 2000; Lenius et al., 2009). The placement site was identified by positioning the
thumb underneath the chin (Crary & Groher, 2000), and asking the participant to elevate their tongue to the hard palate. The active electrodes were placed parallel to the fibers of the submental musculature to maximize the amplitude of the signal (Lenius et al., 2009; Stepp, 2012). This placement is illustrated in Figure 6. The electrodes were fastened to undersurface of the chin (Huckabee et al., 2005), using the adhesive on the electrode patch. This placement of the electrodes detected the combined EMG activity from the submental muscles (Huckabee & Steele, 2006).

*Figure 6. Placement of sEMG electrode.*
Placement of the three-bulb tongue array. For the lingual elevation condition and swallowing tasks, the bulb array was placed on the midline of the hard palate in such a manner that the anterior bulb was located at the alveolar ridge. The three-bulb tongue array was positioned in the oral cavity so as to maximize participant comfort, and prevent eliciting the gag response. The tongue bulb array was placed by the examiner, and was maintained in position by using the “spine” of the array. When placed inside the oral cavity, the bulb array was inverted so that the bulbs faced the tongue. The researcher placed a mark at the seventh centimeter on the spine of the tongue bulb (from the bulb end) using tape. This 7 cm mark was positioned just anterior to the participant’s closed lips (Gingrich et al., 2012), to ensure consistency in the placement of the tongue bulb in the oral cavity. For two participants only two bulbs were placed inside the oral cavity instead of three. One participant experienced gagging when all three bulbs were placed in the oral cavity, and for other participant the anterior bulb was not recording optimally. All the other participants were able to tolerate the three-bulb tongue array positioning in the oral cavity during the lingual elevation condition.

For the lingual depression condition, the array was placed intraorally such that the furthest bulb from the “spine” of the array was placed at the junction between the lower incisors and gums. For this condition, the participant was asked to exert pressure against the specified bulb that was supported partially by the mandible. For the lingual protrusion conditions, the positioning of the bulb array was based on that adopted by Clark et al. (2009). During this condition, the bulb array was positioned against a tongue depressor for support, and the tongue depressor was placed between the upper and lower incisors
(Clark et al., 2009). All the participants were able to tolerate the three-bulb tongue array positioning for the lingual protrusion and depression conditions.

**Bite block and placement of sEMG electrode over the masseter.** A small bite block (2 mm) was used to minimize the influence of the jaw closing muscles on lingual pressures and submental sEMG. Solomon and Munson (2004) have observed that the lingual pressures were highest when no or a very small bite block (2 mm height) was used during intraoral lingual elevation conditions. However, Palmer et al. (2008) has stated that using a bite block during such lingual press conditions might affect the “recruitment patterns” (p. 833) of the muscles of the oral cavity that are involved in the generation of such pressures. For these experiments, a small bite block of 2 mm height was placed between the upper and lower molars if excessive activity of the masseter was observed, and if the placement did not interfere with the intraoral movement of the tongue.

For all the participants, a sEMG electrode was placed over the masseter muscle on the lower jaw to ensure that the activation of the masseter during the three MIP lingual conditions did not excessively exceed that of the baseline activity. During sEMG, the mean resting potential of the masseter is expected to be approximately 2.5 µV (Vaiman et al., 2004b). In this study, it was observed that for all participants the average masseter activation during the MIP lingual conditions was observed to be < 4.5 µV, after instructing the participant “not to tighten, but relax” their jaw muscles.

**Experimental protocol.** During the course of the experiments, the participants were asked to indicate any discomfort by raising their hand. This was to ensure maximum
participant comfort during the three lingual conditions. Baseline sEMG or the resting potential for the submental muscles were measured by the instrument for 0.5 seconds when the participant was at rest, prior to the lingual conditions (Vaiman et al., 2004b; Wheeler-Hegland et al., 2008). Resting baseline potentials represents the ‘quiet’ electrical activity of the muscles at the site of the electrodes, and is observed to range from 0 to 4 \( \mu \text{V} \) (Crary & Groher, 2000; Vaiman et al., 2004b). To ensure resting potentials within this range of values, the participants were seated upright with their feet planted firmly on the ground (Crary & Groher, 2000). The sEMG baseline or resting potentials of the submental muscles for all the participants did not exceed 4.2 \( \mu \text{V} \).

After positioning the tongue bulb array in the oral cavity, the following swallow trials were completed by the participant:

- Three trials of dry (saliva) swallows: Three trials were completed during which the participant swallowed his/her saliva when the researcher provided the instruction, “swallow.” A brief interval of rest (5 seconds) was provided between the trials.

- Three trials of effortful swallows: The researcher first explained an effortful swallow, and then instructed the participant in the following manner, “When you swallow, squeeze the muscles in your mouth and throat as hard as you can” (Logemann, 1998, p. 221). Submental sEMG measures and lingual pressures were recorded for three trials of effortful swallow, each trial separated by brief intervals of rest (5 seconds).
The submental sEMG and anterior lingual pressures recorded from these swallow trials were used for reference purposes and were not included for statistical analysis. The three MIP conditions involving the tongue tip were explained to the participant after the swallowing tasks. The intraoral isometric lingual conditions, during which the participant exerted maximum lingual pressure in each direction (elevation, protrusion, and depression), were carried out in the following manner:

- **MIP lingual elevation:** For recording submental sEMG and lingual pressures during the MIP lingual elevation condition, the participant was shown the bulb against which maximum tongue pressure was to be exerted. The following instructions were given to each participant: “Place your tongue tip on the first tongue bulb. When I say go, push your tongue as hard as you can against the first bulb. Continue to do so until I say stop.” The instructions are similar to that used by Clark and Solomon (2012) and Lazarus et al. (2003).

- **MIP lingual protrusion:** For recording the measures during the lingual protrusion condition, a protocol similar to that used by Clark et al. (2009) was adopted. Prior to the trials, the participant was shown the bulb against which maximum lingual pressure was to be exerted on. The instructions for this condition were similar to that used during the lingual elevation condition.

- **MIP lingual depression condition:** For the lingual depression condition, the bulb on which maximum lingual pressure was to be exerted on was again be shown to the participant. The instructions for this condition were also similar to that used for the lingual elevation condition.
For the lingual elevation, protrusion, and depression conditions, the participants completed practice trials to ensure that they understood the nature of the tasks, and the instructions provided by the researcher. After the practice trials, each participant completed three trials for each lingual condition. Each MIP lingual condition trial lasted for 4 seconds, and the participants were provided with rest intervals (two minutes) between each trial (Lazarus et al., 2003). Also, during the trials, the researcher verbally encouraged the participant as necessary to exert maximum lingual pressure (Clark et al., 2009 & Clark & Solomon, 2012). The order of the experimental protocol for the lingual conditions (elevation, protrusion, and depression) was counterbalanced to control for order effects.

Data Analysis

Submental sEMG measurements. When reporting submental sEMG for each trial of the MIP lingual conditions, the instrument computed the maximum sEMG measure from the selected first to fourth second, and these measures were corrected for the resting baseline potential. Considering data from the first to the fourth second ensured that the best performance of the participant was captured, especially taking into consideration the possibility of delayed participant response to the instructions. The maximum submental sEMG value for each trial represents the highest or maximum activation of the submental muscles during a specific lingual condition (Lenius et al., 2009).

To reduce variability, and to improve reliability in interpreting sEMG results, the majority of research in this area has recommended normalization of sEMG measures with
respect to a reference value for each participant (Huckabee & Steele, 2006; Stepp, 2012; Wheeler-Hegland et al., 2008; Yeates et al., 2010). For this study, the reference value chosen was the highest sEMG measure among the three trials of effortful swallow (Wheeler-Hegland et al., 2008). The submental sEMG measures recorded during the MIP lingual conditions were normalized with respect to this value. For example, in an older participant, the highest sEMG measure during the effortful swallow trials was 76.54 µV, which was given a value of 100. Thus, for the same participant, the maximum sEMG during the MIP lingual condition (elevation) was 22.64, which was re-scaled to a value of 29.58 (100*22.64/76.54), with respect to the reference value.

For comparison and data analysis, the normalized maximum submental sEMG over the three trials for each lingual condition was averaged. This value represents the average maximum submental muscle activation during each of the isometric lingual conditions (elevation, protrusion, and depression).

**Lingual pressure measurements.** Recording peak lingual pressures during swallowing and MIP lingual conditions is considered to be an objective measure of lingual strength (Clark et al., 2003; Robbins et al., 2007). In accordance with the majority of research in this area (Clark et al., 2003; Clark & Solomon, 2012; Gingrich et al., 2012; Lazarus et al., 2003; Robin, Goel, Somodi, & Luschei, 1992; Youmans et al., 2009; Youmans & Steirwalt, 2006), the maximum or peak lingual pressure from each trial during the three MIP lingual conditions was recorded. Specifically, the instrument computed and displayed the peak lingual pressure (in mmHg) from the same duration as that selected for sEMG analysis (the first to the fourth second of the 4-second trial). The
values in mmHg were converted to kilopascal (kPa) by multiplying the recorded value in mmHg with 0.133 to facilitate comparison with research in the area. For each lingual condition, the average of peak lingual pressures across the three trials was calculated, and this value represented the peak lingual pressure for that MIP lingual condition.

**Reliability**

The primary researcher established intrajudge reliability by re-measuring the dependent measures from the raw data of 15% of the participants. A second graduate student trained in measuring the dependent measures established interjudge reliability by recording the same measures from the raw data of 15% of the participants. To establish intra-judge reliability, intraclass correlation coefficient was computed for the two sets of measurements for submental sEMG and lingual pressures, and was established to be 0.99 ($p < 0.01$) and 0.99 ($p < 0.01$), respectively. Similarly, for interjudge reliability, the intraclass correlation coefficient for the two sets of measurements for submental sEMG and lingual pressures was 0.99 ($p < 0.01$) and 0.99 ($p < 0.01$), respectively.

The second rater also established procedural reliability by independently recording the time for each trial of the MIP lingual conditions using a stopwatch for 15% of the participants. The procedural reliability was calculated as follows: Total number of agreements (matches) between the primary and secondary rater divided by the total number of agreements and disagreements, multiplied by 100 (Kuoch & Mirenda, 2003). This value was computed to be 86.5%.
Statistical Analysis

SPSS v18.0 (SPSS Inc., Chicago, IL) was used for all the statistical analyses. The research designs and analyses for each research question are described below:

Research aim I. To describe submental muscle activation using surface electromyography (sEMG) and lingual strength using the three-bulb tongue array in young (18 to 40 years) and older (60 years and above) healthy adults during the swallowing tasks and during the following MIP lingual conditions involving the anterior tongue: tongue elevation to the hard palate, tongue protrusion, and tongue depression in the oral cavity. For this research aim, descriptive statistics such as mean and standard deviation was used to describe submental sEMG measures and lingual pressures during the MIP lingual conditions.

Research aim II. Determine the effects of age (young and old), gender (male and female), and lingual conditions (elevation, protrusion, and depression) on submental muscle activation. For this analysis, the normalized maximum sEMG measures were log transformed, as the nontransformed data were not normally distributed. A mixed three-way analysis of variance was used to examine the effects of the independent variables: age, gender (between subjects factors with two levels), and lingual condition (within subjects factor with three levels), on the dependent measure (log transformed normalized maximum sEMG). For post hoc tests, Bonferroni correction was applied to account for multiple comparisons ($p = 0.016$) among the levels of lingual conditions.

Research aim III. Determine the effects of age (young and old), gender (male and female), and lingual conditions (elevation, protrusion, and depression) on lingual
strength. A mixed design three-way analysis of variance was also used for this analysis. The independent variables for this design were age, gender (both between-subjects factors with two levels), and lingual condition (a within-subjects factor with three levels). The dependent variable was the mean peak lingual pressure. Post hoc analysis was done by applying the Bonferroni correction ($p = 0.016$), to account for multiple comparisons.

**Research aim IV.** Determine the correlation between submental sEMG and the lingual pressures generated for each of the three lingual conditions. For each of the three lingual conditions, Pearson product-moment correlation coefficient was computed to determine the overall relation between the two dependent variables ($p < 0.05$), and that between the measures in each of the groups (young men, young women, older men, and older women) during each of the MIP lingual conditions.
Chapter 4: Results

Research Aim I: Submental Muscle Activation and Lingual Pressures

The first aim of this study was to describe submental muscle activation, using sEMG, and lingual pressures during MIP conditions involving lingual elevation, protrusion, and depression, and during swallowing tasks in healthy adults using descriptive statistics. The maximum submental sEMG was first recorded during swallowing tasks that consisted of dry and effortful swallows, followed by the MIP lingual conditions. The descriptive statistics summarizing the findings have been displayed in Table 1 and 2. Table 1 provides the mean and standard error of the normalized maximum sEMG measures across all the groups for MIP lingual conditions and swallowing tasks. Table 2 summarizes the mean and standard error of the normalized maximum sEMG measures for age and gender groups across MIP lingual conditions and swallowing tasks.
Table 1

*Mean and Standard Error of Normalized Maximum sEMG for Maximum Isometric Pressure Lingual Conditions and Swallowing Tasks*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MIP conditions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lingual elevation</td>
<td>21.34</td>
<td>4.10</td>
</tr>
<tr>
<td>Lingual protrusion</td>
<td>35.01</td>
<td>4.13</td>
</tr>
<tr>
<td>Lingual depression</td>
<td>24.26</td>
<td>2.86</td>
</tr>
<tr>
<td><strong>Swallowing tasks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effortful swallow</td>
<td>86.25</td>
<td>1.32</td>
</tr>
<tr>
<td>Dry swallow</td>
<td>57.64</td>
<td>3.92</td>
</tr>
</tbody>
</table>
Table 2

*Mean Normalized Maximum sEMG for the Two Age and Gender Groups During Maximum Isometric Pressure Lingual Conditions and Swallowing Tasks*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Young</th>
<th>Older</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>MIP conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lingual elevation</td>
<td>9.76 (7.95)</td>
<td>14.19 (8.28)</td>
</tr>
<tr>
<td>Lingual protrusion</td>
<td>22.76 (8.01)</td>
<td>36.57 (8.33)</td>
</tr>
<tr>
<td>Lingual depression</td>
<td>18.20 (5.54)</td>
<td>23.19 (5.77)</td>
</tr>
<tr>
<td>Swallowing tasks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effortful swallow</td>
<td>88.54 (2.56)</td>
<td>82.16 (2.67)</td>
</tr>
<tr>
<td>Dry swallow</td>
<td>46.93 (7.60)</td>
<td>58.22 (7.91)</td>
</tr>
</tbody>
</table>

*Note.* The values in parentheses are the standard errors.

Peak lingual pressures from the anterior tongue were recorded during MIP lingual conditions, and during swallowing tasks in these young and older healthy participants.

Table 3 and 4 provides the descriptive statistics for peak lingual pressures.
Table 3

*Mean and Standard Error of Anterior Peak Lingual Pressure (kPa) for Maximum Isometric Pressure Lingual Conditions and Swallowing Tasks*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MIP conditions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lingual elevation</td>
<td>38.75</td>
<td>1.86</td>
</tr>
<tr>
<td>Lingual protrusion</td>
<td>30.67</td>
<td>1.67</td>
</tr>
<tr>
<td>Lingual depression</td>
<td>42.26</td>
<td>2.10</td>
</tr>
<tr>
<td><strong>Swallowing tasks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effortful swallow</td>
<td>37.52</td>
<td>1.76</td>
</tr>
<tr>
<td>Dry swallow</td>
<td>25.53</td>
<td>2.86</td>
</tr>
</tbody>
</table>
Table 4

*Mean Anterior Peak Lingual Pressure (kPa) for the Two Age and Gender Groups During Maximum Isometric Pressure Lingual Conditions and Swallowing Tasks*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Young Male</th>
<th>Young Female</th>
<th>Older Male</th>
<th>Older Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIP conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lingual elevation</td>
<td>49.52 (3.61)</td>
<td>38.95 (3.75)</td>
<td>28.60 (3.75)</td>
<td>37.92 (3.75)</td>
</tr>
<tr>
<td>Lingual protrusion</td>
<td>32.78 (3.23)</td>
<td>31.11 (3.36)</td>
<td>27.10 (3.36)</td>
<td>31.70 (3.36)</td>
</tr>
<tr>
<td>Lingual depression</td>
<td>45.91 (4.08)</td>
<td>46.51 (4.24)</td>
<td>35.24 (4.24)</td>
<td>41.31 (4.24)</td>
</tr>
<tr>
<td>Swallowing tasks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effortful swallow</td>
<td>47.06 (3.41)</td>
<td>44.01 (3.55)</td>
<td>26.81 (3.55)</td>
<td>32.19 (3.55)</td>
</tr>
<tr>
<td>Dry swallow</td>
<td>28.89 (5.56)</td>
<td>23.36 (5.79)</td>
<td>27.59 (5.79)</td>
<td>22.27 (5.79)</td>
</tr>
</tbody>
</table>

*Note.* The values in parentheses are the standard errors.

**Research Aim II: Effects of Age, Gender, and Lingual Condition on Submental**

**Muscle Activation as Measured by sEMG**

For all analyses, the log transformed normalized maximum submental sEMG measures were used, for reasons explained in the previous section.

**Age and gender.** There was no significant difference in mean maximum submental sEMG between the young \( M = 1.20, \ SE = 0.07 \) and older \( M = 1.31, \ SE = \)
0.07) healthy participants during MIP lingual conditions, $F(1, 45) = 1.53, p = 0.22$, partial $\eta^2 = 0.03$.

However, women displayed significantly greater maximum submental sEMG activation than men during the MIP lingual conditions, $F(1, 45) = 4.43, p = 0.04$, partial $\eta^2 = 0.09$. The log transformed mean maximum submental activation for women was 1.36 ($SE = 0.07$), and that for men was 1.16 ($SE = 0.07$). No significant interaction between age and gender for submental muscle activation was observed for the three lingual conditions, $F(1, 45) = 0.005, p = 0.95$, partial $\eta^2 < 0.01$. Figure 7 and 8 display the mean log transformed normalized maximum sEMG during the three lingual conditions for age and gender, respectively.
Figure 7. Mean log transformed normalized maximum submental surface electromyography measures during the three maximum isometric pressure lingual conditions for young and older healthy adults. There was no significant difference in mean maximum submental muscle activation between young and older healthy participants across the three maximum isometric pressure lingual conditions.
Figure 8. Mean log transformed normalized maximum submental surface electromyographic measures during the three maximum isometric pressure lingual conditions for men and women. Women displayed significantly greater mean maximum submental muscle activation than men across the three maximum isometric pressure lingual conditions.

**Lingual condition.**

There was a significant difference in the mean maximum submental muscle activation for the three MIP lingual conditions, $F(2, 90) = 40.88, p < 0.01$, partial $\eta^2 = 0.48$. On post hoc analysis, the mean normalized maximum sEMG during lingual
elevation ($M = 1.11, SE = 0.06$) was significantly less than that during lingual protrusion ($M = 1.42, SE = 0.05$), $t(48) = -9.37, p < 0.01$. The mean sEMG measure during lingual elevation was also significantly less than that during lingual depression ($M = 1.24, SE = 0.05$), $t(48) = -3.48, p < 0.01$. Maximum submental muscle activation during the MIP lingual protrusion condition was greater than during lingual depression, $t(48) = 5.42, p < 0.01$. In summary, maximum submental muscle activation was greatest during the lingual protrusion condition, followed by the lingual depression condition, and least during the lingual elevation condition. These results are displayed in Figure 9.
Figure 9. Mean log transformed normalized maximum submental surface electromyographic measures during the three maximum isometric pressure lingual conditions. Mean maximum submental muscle activation was greatest during the lingual protrusion condition, followed by the lingual depression condition, and least during the lingual elevation condition.

The interaction between lingual condition and age was also significant, $F(2, 90) = 3.19$, $p = 0.046$, partial $\eta^2 = 0.07$. During lingual elevation, there was no significant difference in maximum submental muscle activation between the young and older groups ($M_y = 0.99$, $SE = 0.06$; $M_o = 1.22$, $SE = 0.10$), $t(36.05) = -1.95$, $p = 0.059$. Similar results
were also observed between the younger and older groups during lingual protrusion ($M_Y = 1.39, SE = 0.06; M_O = 1.46, SE = 0.08$), and lingual depression ($M_Y = 1.21, SE = 0.06; M_O = 1.27, SE = 0.09$): $t(47) = -0.76, p = 0.45$, and $t(47) = -0.65, p = 0.52$, respectively. Figure 10 illustrates the interaction between lingual condition and age. Interactions between lingual condition and gender, and among lingual condition, age, and gender were not significant, $F(2, 90) = 0.66, p = 0.52$, partial $\eta^2 = 0.014$, and $F(2, 90) = 0.56, p = 0.57$, partial $\eta^2 = 0.012$, respectively.
Figure 10. Interaction between age and lingual condition for log transformed normalized maximum submental surface electromyographic measures. During the maximum isometric pressure lingual elevation, protrusion, and depression conditions, there were no significant differences in mean maximum submental muscle activation between young and older healthy adults.
Research Aim III: Effect of Age, Gender, and Lingual Condition on Lingual Strength as Measured by Lingual Pressures

As discussed in the previous section, peak lingual pressures in kPa have been used for all the analyses.

**Age and gender.** For the MIP conditions, the young healthy adults exhibited significantly higher mean peak lingual pressure than the older group, $F(1, 45) = 4.49, p = 0.04$, partial $\eta^2 = 0.09$. The mean peak lingual pressure in the young group was 40.80 kPa ($SE = 2.36$), while that of the older group was 33.66 kPa ($SE = 2.41$). Mean peak lingual pressures for the two age groups during the three MIP lingual conditions are displayed in Figure 11.
Figure 11. Mean peak lingual pressures (kPa) during the three maximum isometric pressure lingual conditions for young and older healthy adults. Young healthy adults exhibited significantly higher mean peak lingual pressure than the older group during the three maximum isometric pressure lingual conditions.

There was no significant difference in mean peak lingual pressure between men ($M = 36.54, SE = 2.36$) and women ($M = 37.92, SE = 2.41$), $F(1, 45) = 0.17, p = 0.68$, partial $\eta^2 = 0.004$. Figure 12 illustrates the mean peak lingual pressures for men and
women during the three MIP lingual conditions. There was also no significant interaction between age and gender, $F(1, 45) = 2.44$, $p = 0.13$, partial $\eta^2 = 0.05$.

**Figure 12.** Mean peak lingual pressures (kPa) during the three maximum isometric pressure lingual conditions for men and women. There was no significant difference in mean peak lingual pressure between men and women during the three maximum isometric pressure lingual conditions.
**Lingual condition.** There was a significant difference in mean peak lingual pressure during the three MIP lingual conditions, $F(2, 90) = 33.19, p < 0.01$, partial $\eta^2 = 0.42$. Mean peak pressure during lingual elevation was significantly greater than that during lingual protrusion, $t(48) = 4.83, p < 0.01$. Mean peak lingual pressures during the lingual protrusion condition also significantly lower than that during the lingual depression condition, $t(48) = -8.42, p < 0.01$. However, there was no significant difference between peak lingual pressures during the lingual elevation and lingual depression conditions, $t(48) = -2.18, p = 0.03$. To summarize, the mean peak lingual pressure was highest during the lingual depression condition, followed by the lingual elevation condition, and least during the lingual protrusion condition. The mean and standard errors of the peak lingual pressures for each lingual condition is provided in Table 3, and Figure 13 displays the mean peak lingual pressures for the three lingual conditions.
Figure 13. Mean peak lingual pressure (kPa) during the three maximum isometric pressure lingual conditions. Mean peak lingual pressure during lingual depression and lingual elevation was significantly higher than that during lingual protrusion. There was no significant difference in mean peak lingual pressure between lingual depression and lingual elevation.

There was a significant interaction between age and lingual condition, $F(2, 90) = 4.28, p = 0.02$, partial $\eta^2 = 0.09$, as displayed in Figure 14. It was established that during lingual elevation, the young adults ($M = 44.45$ kPa, $SE = 2.93$) exhibited higher peak lingual pressures than the older adults ($M = 33.26$ kPa, $SE = 2.57$), $t(47) = 2.86, p < 0.01$. 
There were no significant differences in mean peak lingual pressures between the young and older adults for lingual protrusion ($M_y = 31.98$ kPa, $SE = 1.98$; $M_o = 29.40$ kPa, $SE = 2.66$) and lingual depression ($M_y = 46.20$ kPa, $SE = 2.61$; $M_o = 38.31$ kPa, $SE = 3.25$), $t(47) = 0.78$, $p = 0.44$, and $t(47) = 1.90$, $p = 0.06$, respectively. The interaction between gender and lingual condition was not significant, $F(2, 90) = 0.91$, $p = 0.41$, partial $\eta^2 = 0.02$. However, the triple interaction between age, gender, and lingual condition was significant, $F(2, 90) = 3.88$, $p = 0.02$, partial $\eta^2 = 0.08$. 
Figure 14. Interaction between age and lingual condition for mean peak lingual pressure. During the lingual elevation condition, young healthy adults exhibited significantly higher mean peak lingual pressure than the older group. There were no significant differences in mean peak lingual pressure between the young and older healthy adults during the lingual protrusion and lingual depression conditions.

Research Aim IV: Correlation Between Submental sEMG Measures and Lingual Pressures

Lingual elevation. On averaging the measures across all participants in both the age groups, there was a significant positive correlation between the maximum submental
sEMG and the peak lingual pressures during the MIP condition involving lingual elevation, $r = 0.35, p < 0.05$. Thus, during lingual elevation submental muscle activation increased as peak lingual pressure increased. When looking individually at the four groups based on age and gender, there was no significant relation between maximum submental muscle activation and peak lingual pressure in young men and women, and in older men, $r = 0.30, p = 0.35$; $r = 0.39, p = 0.21$; and $r = 0.09, p = 0.79$, respectively. However, significant correlations were observed between these measurements in older women, $r = 0.73, p < 0.01$. Thus, in older women, for the MIP condition involving lingual elevation, increased submental muscle activation was associated with an increase in peak lingual pressures.

**Lingual protrusion.** Similarly, for the lingual protrusion condition, when averaging the measures across all participants, a significant positive correlation was observed between the dependent measures, $r = 0.47, p < 0.01$. An increase in maximum submental sEMG can be associated with an increase in peak lingual pressures during the lingual protrusion condition. No significant relation was observed between peak lingual pressures and maximum submental sEMG in younger men and women during the MIP protrusion condition, $r = 0.31, p = 0.30$, and $r = 0.26, p = 0.42$, respectively. Similar observations were noted in older men, $r = 0.39, p = 0.21$. In older women, there was a significant relationship between the measures for lingual protrusion, $r = 0.82, p < 0.01$. It can be stated that in older women, during the MIP lingual protrusion condition, an increase in maximum submental muscle activation can be associated with an increase in peak lingual pressures.
**Lingual depression.** For MIP conditions involving lingual depression, there was no relation between the maximum submental muscle activation and peak lingual pressure, $r = 0.18, p = 0.23$. Similarly, no significant correlations were present between submental sEMG and lingual pressure measures during the MIP condition involving lingual depression in young men and women, and in older men and women, $r = 0.35, p = 0.24$; $r = 0.08, p = 0.80$; $r = -0.17, p = 0.60$; and $r = 0.54, p = 0.07$. 
Chapter 5: Discussion

The first aim of this study was to describe submental muscle activation, using sEMG, and lingual pressures during three intraoral MIP lingual conditions involving lingual elevation, protrusion, and depression in healthy adults using descriptive statistics. The second research aim was to determine the effects of age (young and old), gender (male and female), and intraoral MIP lingual conditions (elevation, protrusion, and depression) on submental muscle activation. Each hypothesis was accepted or rejected as follows: (a) The hypothesis that older healthy adults would exhibit lower submental muscle activation was rejected; (b) the hypothesis that men would exhibit greater submental muscle activation was rejected; and, (c) the hypothesis that the three lingual conditions would have differential effects on submental sEMG measures was accepted. The third research aim was to determine the effects of age, gender, and intraoral MIP lingual conditions on lingual strength as measured by lingual pressures. The hypothesis (a) that younger healthy participants would exhibit higher lingual pressures was accepted, (b) that men would exhibit higher lingual pressures was rejected, and (c) that the three lingual conditions would have differential effects on lingual pressures was accepted. The fourth research aim was to determine the relationship between lingual pressures and submental sEMG during the three intraoral MIP lingual conditions. The hypothesis that a positive linear relationship would be observed between submental sEMG and lingual pressures was accepted for two of the three intraoral lingual conditions.
Submental Muscle Activation as Measured by sEMG

Submental sEMG provides important physiological information regarding a set of muscles that form an integral part of the oropharyngeal mechanism. In particular, during swallowing the contraction of the submental muscles contribute to the airway protection mechanism by facilitating the elevation of the hyoid and larynx (Dodds et al., 1990; Kim & McCullough, 2008; Wheeler-Hegland et al., 2008). The activation of submental muscles has been extensively examined using sEMG (Huckabee & Steele, 2006; Vaiman et al., 2004b; Wheeler-Hegland et al., 2008; Yeates et al., 2010). One of the aims of this study was to examine submental muscle activation during MIP lingual conditions, and during swallowing tasks. Previously, activation of the submental muscles has been documented during MIP lingual elevation conditions (Lenius et al., 2009; Palmer et al., 2008; Yoshida et al., 2007). However, this study explored and quantified submental muscle activation during MIP lingual conditions involving protrusion and depression of the anterior tongue, in addition to during swallowing tasks, and the MIP lingual elevation condition.

Maximum submental muscle activation (as measured by sEMG) during MIP lingual conditions were submaximal when compared to that recorded during swallowing tasks (effortful and dry swallows, see Table 1). It should be remembered that during swallowing tasks the submental sEMG represents submental muscle activation during not only the oral stage of swallowing, but also that during the pharyngeal stage. The higher maximum submental sEMG during the swallowing tasks can be attributed to hyolaryngeal excursion, because maximal contraction of the submental muscles is
observed during the elevation of the hyoid (Drake et al., 2005). Submental sEMG measures are established to be most closely associated with hyoid and laryngeal excursion during swallowing (Crary et al., 2006). Thus, the activation of the submental muscles during the MIP lingual conditions does not represent the muscles in their state of “maximum voluntary contraction” (Stepp, 2012, p.1236).

**Effects of age.** For the MIP lingual conditions, there was no significant difference in maximum submental muscle activation between the young and older healthy adult participants. This study hypothesized that the young group would exhibit greater maximum submental muscle activation than the older group, which was based on the assumption that the changes associated with aging that affect lingual muscles would also have similar effects on other muscles involved in oropharyngeal swallowing (McComas, 1998). Older healthy individuals also exhibited reduced anterior hyoid displacement (Kim & McCullough, 2008) and reduced hyoid elevation (Logemann et al., 2000), during swallowing, which have been attributed to the effects of aging on submental muscle activation, thereby reduced muscle reserve. Perhaps, the combined activity of submental muscles, as measured by sEMG, is not sensitive enough to reflect the changes in muscle structure and function secondary to aging. Using a more direct form of measurement, such as intramuscular EMG, to measure the activation of individual muscles that form the submental musculature could possibly reveal the effects of aging on submental muscle activation.

When looking at previous research that has examined maximum submental muscle activation, it is difficult to develop a range of “normative values,” because studies
have used different reference values for normalizing sEMG measures (Huckabee & Steele, 2006; Wheeler-Hegland et al., 2008; Yeates et al., 2010). In this study, each participant’s sEMG measures were normalized with respect to the highest maximum sEMG recorded during the effortful swallow trials. On reviewing the maximum sEMG measures, it can be inferred that healthy adults should be capable of producing a maximum submental sEMG of 30.66 µV during MIP lingual conditions, which corresponds to a normalized maximum submental sEMG of 20.79. This is based on the fact that mean maximum sEMG in the young and older groups was 30.66 µV and 31.48 µV, respectively. Furthermore, using sEMG to measure maximum submental muscle activation during MIP lingual conditions in individuals with dysphagia could help in the identification of a “cut-off” score. Reduced submental muscle activation during these MIP lingual conditions would also suggest reduced activation during swallowing, which in turn could be indicative of dysphagia.

**Effects of gender.** Although it was hypothesized that greater maximum submental muscle activation would be observed in men, it was found that women exhibited greater maximum submental sEMG during the MIP lingual conditions. There has been very limited research that has examined differences in submental sEMG between healthy men and women during MIP lingual conditions. It is probable that women exhibited greater effort in completing the MIP lingual conditions, which was reflected in their higher sEMG measures. Greater activation of the muscles that form the submental musculature will have to be ascertained by using intramuscular EMG, which will provide definite information about amplitudes and activation patterns of individual
muscles. However, it is interesting to observe that the greater effort exhibited by women did not translate into significantly higher lingual pressures as well.

Previous research has observed that in healthy women, the muscular reserve was maintained as they aged, suggesting that women may exhibit “greater flexibility in the oropharyngeal mechanism” (Logemann, Pauloski, Rademaker, & Kahrilas, 2002, p. 441). The authors also suggest that this greater flexibility would result in greater ability in women to “. . . develop more successful behavioral adjustments to compensate for aging than men can” (Logemann et al., 2002, p. 441). This hypothesis may also account for the greater maximum submental muscle activation in women than in men during the MIP lingual conditions.

**Effects of lingual condition.** Again, the majority of research in this area has explored submental muscle activation using intramuscular EMG or sEMG during swallowing tasks, and during conditions involving lingual elevation to the hard palate (Huckabee & Steele, 2006; Palmer et al., 2008; Lenius et al., 2009; Steele & Huckabee, 2007; Yeates et al., 2010). Examining the differential activation of submental muscles during the three lingual conditions (lingual elevation, protrusion, and depression) in this study helped to establish a baseline for submental sEMG measures. Such a step is essential before determining whether a lingual strengthening exercise paradigm adopting such lingual conditions would result in improving submental muscle activation.

This study indicated differential activation of the submental muscles during the three MIP lingual conditions. MIP lingual protrusion condition resulted in highest maximum submental sEMG, while lingual elevation resulted in the lowest. To better
understand the nature of submental muscle activation as measured by sEMG, during these lingual conditions, let us examine the submental and lingual muscles activated during these conditions. During the MIP lingual protrusion condition, the submental muscle that is most likely to be activated is the mylohyoid, which upon contraction would provide support to the floor of the mouth (Drake et al., 2005). Among the lingual muscles, the genioglossus, vertical, and transverse muscles would be responsible for protrusion of the anterior tongue (Drake et al., 2005; Pittman & Bailey, 2009). During the MIP lingual elevation condition, maximal activation of the genioglossus, anterior belly of the digastric, and mylohyoid would be observed (Lenius et al., 2009; Palmer et al., 2008). The lingual depression condition would most likely result in the activation of the hyoglossus, the inferior longitudinal muscle, and the mylohyoid (Drake et al., 2005). During the lingual protrusion and lingual depression MIP conditions, activation of the specific submental muscles would have to be confirmed by using intramuscular EMG. As suggested by Lenius et al. (2009), submental sEMG is sensitive to the different submental and lingual muscles activated during lingual movements. As indicated above, the greater number of muscles activated during the lingual protrusion condition may account for the highest maximum submental sEMG during this condition. The differences in maximum submental sEMG for the three lingual conditions may also be attributed to the constitution, location, and course of individual muscles involved, in addition to the number of muscles activated, and the duration of activation.

The activation of and contribution from the submental muscles during MIP lingual elevation conditions has been confirmed by Palmer et al. (2008). Thus, based on
the results of this study (which indicates significantly greater activation of the submental muscles during lingual protrusion and depression when compared to lingual elevation conditions), it can be stated that these muscles are also activated and contribute to lingual protrusion and depression conditions. In addition, activation of these muscles would be necessary to provide a stable base that enables the generation of lingual pressures (Sonies et al., 1984) during any MIP lingual condition.

Another aspect to take into consideration is the duration of the MIP lingual conditions. This study measured maximum submental sEMG during MIP lingual conditions of three seconds. It is important to evaluate whether the maximum activation of the submental muscles is influenced by the duration of the MIP lingual conditions. Perhaps, increasing the duration of the MIP lingual condition in isolation and during lingual strengthening exercise protocols may result in greater activation of the submental musculature (Yoshida et al., 2007), thereby improving the swallow function in individuals with dysphagia.

**Lingual Strength as Measured by Peak Lingual Pressures**

In addition to examining submental muscle activation during MIP lingual conditions involving anterior tongue movement in three directions within the oral cavity, this study also aimed to examine peak lingual pressures for the same conditions. When examining the mean peak lingual pressures (see Table 3), unlike the submental sEMG, the lingual pressures during the MIP lingual conditions are similar to or greater than that during the effortful swallows, and are much higher than that during the dry swallows. The 5 to 16 kPa difference in peak lingual pressures between dry swallows and effortful
swallows or MIP lingual conditions demonstrates the tongue strength reserve (Robbins et al., 1995) or “pressure reserve” (Nicosia et al., 2000, p. M638; Robbins et al., 1995, p. M261). It can also be said that MIP lingual conditions, especially lingual elevation and lingual depression, may represent the state of “maximum voluntary contraction” (Stepp, 2012, p. 1236) of the lingual musculature, as the peak lingual pressures during these conditions exceed that during effortful swallows.

**Effects of age.** The results of this study confirmed the hypothesis that during MIP lingual conditions, young healthy adults exhibited significantly higher peak lingual pressures than the older group. These differences in peak lingual pressures generated by the anterior tongue between the two groups can be attributed to the changes in lingual muscle function with age, and are similar to the observations made by previous research (Clark & Solomon, 2012; Robbins et al., 1995; Youmans & Steirwalt, 2006). As swallowing pressures are submaximal, significantly reduced maximal lingual pressures in the older group does not necessarily influence the swallowing function in the older healthy individuals, but rather is indicative of the reduced “pressure reserve” in older healthy individuals (Robbins et al., 1995, p. M261). Functional reserve is defined as the “. . . difference in pressures generated in MIP tasks compared to swallowing tasks” (Steele, 2013, p. 1), whereas reduced reserve refers to the “. . . reduced maximal movement of a structure, while still accomplishing the desired motor task” (Logemann et al., 2000, p. 1270). In this study, only lingual pressures during maximum isometric lingual conditions were studied in young and older healthy adults, thereby differences in the lingual pressure reserve with age could not be confirmed.
In this study, the mean peak lingual pressures in the younger group was 40.80 kPa and that in the older group was 33.66 kPa, which is lower than that reported in other studies (Nicosia et al., 2000; Stierwalt & Youmans, 2007; Robbins et al., 2005; Youmans & Stierwalt, 2006). The lower peak lingual pressures in both the groups may be attributed to monitoring and maintaining masseter activity during the MIP lingual conditions to below 4.5 µV. During practice trials, it was observed that in some participants when masseter activation was not monitored (i.e., potentials exceeded 5 µV), the peak lingual pressures and submental sEMG were higher than when masseter activation was monitored (i.e., masseter sEMG was less than 4.5 µV). Perhaps, ensuring low levels of masseter activation by using sEMG, specifying instructions to the participant, or by using a small bite block may indeed influence the “recruitment patterns” of the muscles in the oral cavity, and in turn, the peak lingual pressures the individual is capable of generating (Palmer et al., 2008, p. 833). It was interesting to note that during data collection, individuals who were trained musicians or those who were aware of tense oral muscles had difficulty in initially maintaining masseter activation to below 4.5 µV, and required multiple practice trials.

Considering the possibility of identifying a “cut-off” peak lingual pressure that would be suggestive of reduced lingual strength in healthy nondysphagic individuals based on the results of this study and those of others, was an interesting facet. Clark et al. (2003) proposed that using a value of 20 kPa with the IOPI would be specific in identifying oral dysphagia on the basis that healthy adults are capable of producing mean lingual pressures of 20 kPa during dry saliva swallows (Robbins et al., 1995). The latter
was supported by the results of this study, as both young and older healthy participants were capable of producing peak lingual pressures greater than 20 kPa during dry swallows (see Table 4). The lowest peak lingual pressures during the MIP lingual conditions were observed in the older group ($M = 33.7$ kPa), which was still higher than that recorded during the dry swallow trials in the same group. Looking at studies that have examined lingual pressures in individuals with oral dysphagia gives us insight into what value of peak lingual pressure during an MIP lingual condition can be considered as “reduced lingual strength.” Yoshida et al. (2007) has discussed the potential use of such measures during evaluation as an indicator of oral dysphagia.

In their study, Clark et al. (2003) reported that individuals with oral dysphagia exhibited average peak lingual pressures less than 20 kPa. Stierwalt and Youmans (2007) observed peak lingual pressures of 55.01 and 33.55 kPa in older healthy individuals and in older individuals with oral dysphagia, respectively. Individuals defined as having “definite dysphagia” exhibited reduced peak lingual pressures ($M = 10.7$ kPa) during maximum voluntary contraction tasks (Yoshida et al., 2007, p. 62). Stroke patients with dysphagia exhibited mean peak lingual pressures of 35.6 kPa during MIP trials (Robbins et al., 2007). Thus, considering the range of peak lingual pressures reported in previous research, and based on the results of this study, perhaps values between 20 to 25 kPa during MIP lingual conditions could serve as a “red flag.” Peak lingual pressures within this range could indicate reduced lingual strength reserve in older individuals who may not yet overtly exhibit symptoms of oral dysphagia. It may also serve as an indicator of the need to implement lingual strengthening exercises in these individuals. Lingual
strengthening exercises are known to improve lingual strength and reverse the effects of aging on lingual muscle function (Robbins et al., 2005).

**Effects of gender.** There were no significant differences in peak lingual pressures during MIP lingual conditions between men and women. Although, it was hypothesized that the greater biological strength in men would result in greater peak lingual pressures (Crow & Ship, 1996; Gingrich et al., 2012; Stierwalt & Youmans, 2007; Youmans & Stierwalt, 2006), there are studies that support the findings obtained in this study (Clark & Solomon, 2012; Nicosia et al., 2000). Thus, it can be concluded that there were no differences in peak lingual strength between men and women during MIP lingual conditions.

**Effects of lingual condition.** This study examined the effects of intraoral MIP lingual conditions involving the anterior tongue movement in three directions, namely elevation, protrusion, and depression. Previously, MIP generated during the lingual elevation (lingual-palatal contact) condition has been extensively documented (Gingrich et al., 2012; Lenius et al., 2009; Nicosia et al., 2000; Robbins et al., 1995, Stierwalt & Youmans, 2007; Youmans & Stierwalt, 2006). Peak lingual pressures during MIP lingual protrusion conditions have also been studied (Clark et al., 2003; Clark & Solomon, 2012). In this study, the MIP condition involving lingual depression has been introduced. As stated in the previous chapter, the mean peak lingual pressure during this condition was highest, and that during lingual protrusion was the lowest. One of the possible reasons for the lower mean peak lingual pressure during the lingual protrusion condition was due to the nature of the placement of the three-bulb tongue array during this
condition. The three-bulb tongue array was placed against a tongue depressor, and further stabilization was provided with the researcher’s fingers (Clark et al., 2009). The researcher made efforts to ensure that the tongue depressor was provided only the required support and stabilization to ensure the correct placement of instrumentation. However, the total resistance offered to the lingual pressure generated would have been more varied and less consistent than that during the lingual elevation and depression conditions. This is because, for the lingual elevation and depression conditions the resistance offered to the pressure exerted was more consistent and from a fixed structure, namely the roof of the mouth (alveolar ridge and the hard palate), and the mandible, respectively.

The MIP lingual depression condition resulted in the highest peak lingual pressures. It appears that is the first study to examine the effect of a MIP condition involving the downward movement of the anterior tongue on lingual pressures. Intraoral lingual depression involves the downward-movement of the apex of the tongue, which is secondary to the contraction of the inferior longitudinal muscle and the hyoglossus (Drake et al., 2005). All the participants in this study were easily able to execute and complete this lingual condition. For the lingual depression condition, the instructions were simple and straightforward, and the placement of tongue bulb array was easily monitored by landmarks in the oral cavity, thus ensuring consistency. Adopting such a lingual condition in a well-defined MIP lingual exercise protocol may result in greater gains in lingual strength than other lingual conditions that are routinely adopted. For example, in Clark et al. (2003), although baseline peak lingual pressures did not differ
between lingual elevation and lingual protrusion MIP lingual conditions, gains in lingual strength were significantly higher when the healthy adults adopted a lingual protrusion exercise program than the commonly adopted lingual elevation exercise. Perhaps, MIP lingual strengthening exercises adopting the lingual depression condition will result in greater gains in lingual strength, when compared to the existing lingual strengthening exercises.

It was also established that the only significant interaction between age and lingual condition in this study was that for the lingual elevation condition. For this condition, peak lingual pressures in the young group were at least 10 kPa higher than that of the older group, which can be considered to be clinically significant (Clark & Solomon, 2012). However, the differences between the two age groups were less than 10 kPa for lingual protrusion and depression conditions.

**Correlation Between Maximum Submental Muscle Activation and Peak Lingual Pressures**

For the MIP lingual elevation and protrusion conditions, a significant positive relationship was observed between the maximum submental sEMG and peak lingual pressures. During these lingual conditions, the effect size of the relationship between submental sEMG and lingual pressures were moderate. As such, increases in maximum submental muscle activation were associated with increases in peak lingual pressures for these two conditions. However, this relationship was not observed for the MIP lingual depression condition. Yoshida et al. (2007) made similar observations between lingual pressures and submental muscle activity during lingual press conditions that involved
lingual elevation to the hard palate. Such relationships are to be expected considering that “tongue behavior cannot be divorced from hyoid movement, which is directly linked to motion of the mandible” (Hiiemae & Palmer, 2003, p. 415). The primary muscles responsible for tongue behavior are the lingual muscles, whereas those responsible for hyoid movement are the submental muscles.

Lenius et al. (2009) reported low correlations between submental sEMG and lingual pressures during tasks that involved lingual elevation to the hard palate. It is to be noted that the authors indicated that the participants were not instructed to target a specific bulb on the tongue array. In this study, in addition to exploring submental sEMG different lingual conditions, the participants were asked to target a specific bulb during elevation, protrusion, and depression conditions. Perhaps, these methodological differences resulted in the positive correlation between submental sEMG and peak lingual pressures during the lingual elevation and protrusion MIP lingual conditions.

Clinical Implications

At present, the most commonly used intervention strategies designed to increase hyoid excursion are the Mendelsohn maneuver and effortful swallowing (Bulow, Olsson, & Ekberg, 1999; Huckabee et al., 2005; Wheeler-Hegland et al., 2008). Other interventions that influence submental muscle activation include neuromuscular electrical stimulation (Suiter, Leder, & Ruark, 2006), Shaker maneuver, and jaw-opening exercises (Davies, 2012). When hyoid elevation improves, investigators infer that this is due, at least in part, to increased amplitude and duration of submental muscle activation. The possibility of adopting lingual strengthening exercises involving lingual elevation to the
palate to strengthen submental muscles in individuals with dysphagia has been proposed by Palmer et al. (2008) and Yoshida et al. (2007), based on the activation of submental muscles during MIP lingual elevation conditions. Thus, based on the results of the present study, lingual strengthening exercises adopting lingual protrusion and depression MIP conditions would have a greater influence on maximum submental muscle activation than those adopting lingual elevation. This would have to be confirmed by adopting a well-defined lingual exercise protocol involving lingual elevation, protrusion, and depression in individuals with reduced submental muscle activation, and comparing the submental sEMG at the baseline to that after the completion of the protocol. Examining whether lingual strengthening exercises adopting such MIP lingual conditions would have such a “dual effect,” i.e., improving submental muscle activation in addition to lingual strength would benefit individuals with dysphagia. Considering the complexity of dysphagia exercises targeting submental muscle activation (such as the Mendelsohn maneuver) in terms of patient implementation and biofeedback, and the ease of using sEMG for biofeedback during dysphagia treatment, exploring these effects could have clinical implications.

Determining a “cut-off” score that is suggestive of reduced submental activation and lingual strength, thereby indicating a potential risk for swallowing dysfunction, would further encourage the use of sEMG and lingual pressure measures in routine dysphagia assessment and intervention. Identification of such a value or score would also help to define lingual and submental muscle weakness, terms that are subjectively interpreted. Having an objective value to identify or correspond with terminology such as
“slightly,” “moderately,” and “severely” weak (Clark et al., 2003, p. 42) would have significant clinical relevance. Such an application would take advantage of the noninvasive yet objective biofeedback utility of sEMG and the instruments that measure lingual pressures such as the DSW™ by Kay Pentax and the IOPI. Although routinely used during intervention as a biofeedback tool to patients, sEMG and lingual pressure measures have limited application in dysphagia screening and diagnosis. Perhaps, based on further research that establishes methods of normalization that are clinically feasible, range of normative values, and a “cut-off” score indicative of dysphagia, sEMG can be adopted as an easy objective screening tool in clinical settings.

The lingual muscles play a major role in the oral and pharyngeal stages of swallowing (Dodds, 1989). During the MIP conditions, the lingual muscles are involved in isometric contraction and exertion of maximal pressure against a constant resistance. Such conditions involving lingual elevation, protrusion, and lateralization are routinely adopted clinically, especially when oral dysphagia is secondary to lingual muscle weakness. Considering the advantages of the lingual depression condition, such as ease of completion, simple instructions and feedback, consistent resistance, and higher peak lingual pressures than other conditions such as protrusion, it would be worthwhile to clinically implement such an exercise paradigm incorporating this lingual condition. Lingual strengthening exercises involving MIP conditions have been shown to result in increased lingual strength not only during such conditions, but also during swallowing tasks (Robbins et al., 2005). This transfer effect, where functional lingual strength gains are observed following lingual exercises that involve nonswallowing movements, is
attributed to the unique property of individual muscles that constitute the muscular hydrostat (Clark et al., 2009).

Exercises targeting the activation of the submental muscles and lingual strength would indirectly influence physiological events during swallowing, such as hyolaryngeal excursion and bolus propulsion through the oropharynx. Thus, although the movements during the MIP lingual conditions are nonswallowing movements, if the activation and strength of the muscles targeted increases during these lingual conditions, there is a possibility that such effects would be observed in swallowing tasks as well. However, limited evidence exists for such transfer effects (Steele, 2012). When designing a dysphagia intervention program, the ease with which, (a) instructions are provided and implemented, (b) objective measurements are recorded to monitor progress, (c) feedback is provided, and (d) transference to swallowing behaviors are observed, are elements that have to be incorporated to ensure success.

Limitations and Future Directions

The current study assessed maximum submental sEMG and peak lingual pressures in healthy young and older adults during three MIP lingual conditions involving only the anterior tongue. Incorporating lingual conditions that involve other regions of the tongue (such as middle and posterior tongue elevation), and lingual movement in other directions (such as lateralization) may show further effects of lingual condition on submental sEMG and peak lingual pressures. Studying these measures would help in determining the ideal combination(s) of lingual conditions for a strengthening exercise program that would offer the most benefit to individuals with dysphagia by improving
their lingual strength and submental muscle activation, thereby improving their swallowing function.

Additionally, it would be beneficial to develop an instrument similar to the three-bulb tongue array that would facilitate easy placement, provide consistent resistance, and enable the patient to perform MIP conditions involving lingual movement in different directions, and different parts of the tongue. One possible design idea for such an instrument could be a curved spine outside the oral cavity supporting a bulb in the center (for lingual protrusion), and an inferior bulb (for lingual depression), in addition to the regular three-bulb tongue array (for lingual elevation). This would allow the participant to perform the MIP lingual conditions that require lingual movement in different directions, and those involving different regions of the tongue without having to reposition the array. Such an instrument would also ensure consistent, firm resistance to the lingual pressures generated for the MIP conditions. The external curved spine should have an exterior attachment for the clinician or researcher to hold onto, or mount the array, and ensure proper placement.

In addition to comparing maximum submental muscle activation and peak lingual pressures during MIP conditions involving other regions of the tongue, and designing a new instrument to facilitate easy placement and consistent resistance, future research can extend the current study to individuals with dysphagia. First, submental muscle activation and lingual pressure baseline measures during similar MIP lingual conditions can be established. Following this, a strengthening exercise paradigm incorporating lingual conditions in this study can be implemented to assess the effects of such an exercise on
submental muscle activation. This would help in determining whether lingual strengthening exercises do indeed exhibit the “dual effect” proposed in this study.

Examining the correlations between submental sEMG measures and lingual pressures with other objective measurements of oropharyngeal swallowing such as temporal, biomechanical, and manometric measures (similar to the study by Crary et al., 2006) would be clinically relevant. This would facilitate further understanding of the physiological correlates of submental sEMG and/or lingual pressures. Combining methods such as videofluoroscopy, manometry, and sEMG in dysphagia diagnosis may help to shed further light on the exact cause and nature of dysphagia in certain etiologies. Also, developing a clinical diagnostic inventory by combining such objective measurements with other data such as medical status, concomitant health conditions, oral hygiene, analysis of videofluoroscopic examinations, and other indicators of dysphagia would be most relevant.

**Conclusion**

This was the first study to examine and quantify maximum submental muscle activation, as measured by sEMG, during intraoral MIP lingual conditions involving the anterior tongue in healthy adult participants. Also, this study introduced the MIP condition involving lingual depression, thereby expanding the possible lingual conditions that can be incorporated during lingual strengthening exercises for individuals exhibiting reduced lingual strength.

It was established that maximum activation of the submental muscles was greatest during lingual protrusion, and least during lingual elevation. Maximum submental sEMG
was observed to be greater in healthy women, but no differences were observed between young and older adults. Peak lingual pressures were greatest during the MIP lingual depression condition, and least during the lingual protrusion condition. During the MIP lingual conditions, young healthy adults exhibited higher peak lingual pressures than the older adults, however, no differences were observed in peak lingual pressures between men and women.

The results of this study contribute to the literature in the area of swallowing and swallowing disorders by providing normative values for both submental muscle activation and lingual pressures in healthy young and older adults during three MIP lingual conditions. The three lingual conditions in this study are those that are either currently used or those that can be easily implemented in lingual strengthening exercises in patients with dysphagia. Considering the popularity and the routine implementation of lingual strengthening exercises in dysphagia intervention, combining such exercises with sEMG to examine submental muscle activation would not only be easy to implement clinically, but also would further utilize the advantage of the biofeedback application of sEMG.
References


Appendix A: Demographic and Screening Questionnaire

Thank you for participating in this study!

Participant Number:

1. What was your age on your last birthday? _____

2. Are you
   Male _______
   Female _______

3. Which racial group do you belong to?
   a. White _______
   b. African – American _______
   c. American Indian or Alaska native _______
   d. Asian _______
   e. Native Hawaiian or Pacific Islander _______
   f. Some other race (Specify) _______
   g. Multiracial (Two or more races) _______

4. Have you experienced any difficulty swallowing saliva, food, or liquid? (Yes/No) _______
   If you answered ‘yes’ to Question 4, answer questions 4a through 4d, otherwise skip to Question 5.
   4a. How long have you experienced difficulty swallowing? __________
   4b. Describe the swallowing difficulties that you have experienced? (Example: Frequent coughing when drinking water, etc)
   4c. Have you consulted your doctor or been referred to a speech-language pathologist (SLP) for your swallowing impairment (dysphagia)?
   4d. Have you received any treatment for dysphagia? (Swallowing exercises, changes in food / liquid consistency, etc)

5. Have you had any neurological impairments and / or head and neck disorders, and/or neck injuries?
6. Do you have any medical condition, gastrointestinal conditions, or do you take any medication that affects the movement and function of your lips, tongue, jaw, and ability to swallow saliva, food, or liquid? (If yes, please describe /list)

7. Do you have oral sensitivity / oral pain that could affect placing the instrumentation in your mouth and completing the experiments?

8. Have you smoked over the past five years?

9. Please list any medical condition you may have.

*Thank you for your time and patience!*
Appendix B: Overview of the Oral Motor Examination (Logemann, 1989)

Participant Number:

Oral Anatomy
1. Structure of
   - Lips
   - Hard palate (Height & Width)
   - Soft palate
   - Uvula
   - Tongue
2. Presence of scarring (+/-)
3. Structural asymmetry
4. Dentition
   - Dentures (+/-)
5. Oral secretions

Oral-Motor Control Examination
1. Voluntarily open mouth
2. Labial (Lip) Function
   - Assess lip seal at rest
   - Lip spread (say /i/)
   - Lip rounding (say /u/)
   - Alternate between lip spread and rounding (say /i/ and /u/ 5 times)
   - Repetition of the syllable /pa/
   - Say the sentence “Put the papers in the brown pouch”
➢ Take a sip of water: Lip closure during swallowing
➢ Take a sip of water with a straw: Lip seal with a straw

3. Lingual (Tongue) Function
➢ Open your mouth (Observe tongue at rest)
➢ Extend your tongue as far as possible
➢ Pull your tongue back in your mouth as far as possible (Retraction)
➢ Touch the corners of the mouth with the tongue tip (Lateralization)
➢ Rapidly alternate between touching the corners your mouth with your tongue tip
➢ Sweep the sides of your mouth between your cheeks and gums with your tongue (Clearing oral cavity using the tongue)
➢ Open your mouth and touch your tongue to the roof of your mouth (Elevation)
➢ Open your mouth and depress your tongue (Depression in the oral cavity)
➢ Repeating the syllable /ta/ and /ka/
➢ Repeat “Tim took the toy to Tammy”
➢ Repeat “Karen cleaned the kitchen”

4. Soft Palate Function
➢ Say /a/ and sustain /a/ for 5 seconds
➢ Rapidly repeat /a/

5. Laryngeal Function
➢ Assessment of voice quality
➢ Throat clearing / Cough strength
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